A TREATISE ON

STEAM BOILERS:

THEIR STRENGTH, CONSTRUCTION, AND ECONOMICAL WORKING.

"It is but rarely we have had to review a book in which so much sound information is so clearly and compactly stated, or in which there is such an entire absence of all irrelevant matter. Altogether, we regard Mr. Wilson's Treatise as the best work on boilers which has come under our notice."—*Engineering.*

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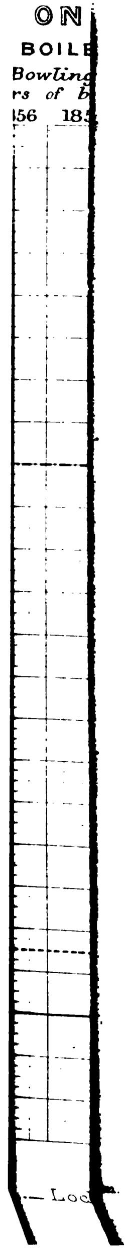
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A TREATISE ON

STEAM BOILERS:

THEIR STRENGTH, CONSTRUCTION, AND ECONOMICAL WORKING.

BY

ROBERT WILSON,

LATE INSPECTOR FOR THE MANCHESTER STEAM USERS' ASSOCIATION FOR THE PREVENTION OF STEAM BOILER EXPLOSIONS AND FOR THE ATTAINMENT OF ECONOMY IN THE APPLICATION OF STEAM.

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ADVERTISEMENT TO SECOND EDITION.

In issuing a Second Edition, the writer begs to state that want of leisure has prevented him from adding fresh matter, and he takes the opportunity to notify that he will be glad to receive any suggestion or information with a view to increase the usefulness of the work in case a future edition may be called for. That the book is likely to be useful, far beyond the writer's expectations, is testified by the flattering manner in which it has been received by the scientific and technical press and by many eminent engineers at home and abroad.

10, St. George's Terrace,
Camp Road,
Leeds, *April*, 1874.

PREFACE TO THE FIRST EDITION.

THIS book does not pretend to give any new facts or opinions upon the subject of which it treats. Any claim to attention it may deserve is based upon its being an attempt to embody the principles of boiler construction and management, together with numerous opinions collected from the writer's experience in boiler inspecting, and from various sources not accessible to the majority of those engaged or otherwise interested in the application of steam.

Many of those opinions advanced, which are founded on experience, may require repeated modification with increased opportunities of observation and as new light is brought to bear on the various questions by further experiments.

As anything like a complete history of boiler progress is beyond the scope of such a small work as this, only a slight sketch of the salient points has been attempted in the first chapter. A complete history, accompanied by remarks pointing out the defects that have led to the disuse of many inventions connected with boiler work, would be of real service to many, for, judging by the frequency of the repetition of old defects, it would appear to be even more important to know what to avoid than what to adopt in designing new boilers.

It is almost impossible in a work like this to mention authorities for all the information given. Where considered necessary, the authorities have been cited; but it may be desirable to specially enumerate the following works that have been most largely drawn upon for information:—Sir W. Fairbairn's "Useful Information for Engineers," Peclet's "Traité de la Chaleur," Professor Rankine's "Steam Engine and other Prime Movers," Mr. D. Kirkaldy's "Experiments on Wrought Iron and Steel," Mr. E. J. Reed's "Shipbuilding in Iron and Steel," and numerous articles in "The Engineer," "Engineering," and "The Mechanics' Magazine."

May, 1873.

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NOTE.

THE writer had in preparation for the First Edition, a chapter on the prices of the various classes of boilers and boiler work; but the sudden rise in the price of materials and labour in 1872, rendered the conclusions based on the average prices for the preceding half-dozen years misleading. The publication of the matter compiled was in consequence abandoned.

The fluctuations in the price of bars and plates may be seen from the diagram preceding the title-page, kindly prepared for the author by Messrs. Heslop, Wilson, & Budden, Engineers and Iron Merchants, Newcastle-on-Tyne.

A TREATISE

ON

STEAM BOILERS.

CHAPTER I.

INTRODUCTORY.

The enormous development attained by the system of employing steam is to be ascribed to its commercial success. Only so long as it continues to be regarded as less costly than other agents will steam retain its present position as a motive power, and for the various purposes in chemical and other manufactures to which it is so largely applied.

Yet there are certain theoretical considerations in connection with the present mode of employing steam, which, regarded in the abstract, clearly indicate that we are by no means justified in concluding that it is the most economical motive power obtainable. Many attempts have, in consequence, been made to replace steam as a prime mover, but without success, as there are found inseparably connected with the employment of all other agents certain practical difficulties which have as yet proved insuperable.

It is not likely we shall soon see these obstacles overcome; and even supposing the successful employment of some more suitable prime mover were rendered practicable to-morrow, it would be so long before the present arrangements could be replaced, that it would still be to our interest to strive to improve our modes of employing the agent we now possess, and to inquire in which direction further progress in its economical application *seems to set.*

It is long since theoretical deductions indicated the economical advantages to be derived from the use of high steam pressures combined with high grades of expansion in the cylinder. The practical difficulties that stood in the way having been gradually and successfully overcome, the result has been the marked changes from the 7-lb. and 10-lb. pressures, so common forty years ago, to the pressures of from 70 lbs. to 150 lbs. at present employed, and the more general employment of the higher pressures will be demanded as the advantages of using steam expansively become more generally recognised.

One of the impediments to progress in this direction is the difficulty of obtaining reliable vessels of sufficient strength and simplicity combined with moderate cost of construction and maintenance for generating and containing the steam.

This difficulty can scarcely be said to be in a fair way of solution, judging from the numerous prodigies boiler engineering has called into existence. It is not intended here to describe the boiler of the future—that cannot be done until experience shall have shown the advantages and defects of the many high pressure tubulous boilers recently introduced, and which are as yet only on their trial—but rather to set forth the principles of construction and management, a knowledge of which is essential to the safe and economical employment of the types of boiler at present chiefly used.

A steam boiler may be defined as a close vessel in which steam is generated. It may assume an endless variety of forms, and can be constructed of various materials.

Boiler making now holds an important position among the practical arts. Its progress has been aided chiefly by the increased facilities of procuring suitable materials, by the improvements made in working them, and also by our better acquaintance with the laws on which the safety and economy of boiler construction and management depend.

In the early days of the steam engine, vessels of copper and cast-iron were used for generating the steam in. It is recorded that structures of stone, and even of wood with internal flues of copper and iron, were at one time employed. These, however, were probably not subject to any but atmospheric pressure. The high price of copper must forbid its ever being used extensively, when cheaper materials are to be found. When pressures of 7 lbs. to 10 lbs. above the atmosphere came into use, cast-iron was found unreliable and treacherous for the boilers as at that time constructed. It was therefore discarded in favour

of wrought iron, which was probably not employed at first in consequence of the difficulty found in working it and in making steam-tight joints. It has, however, of late years become the material employed, almost to the entire exclusion of all others.

Now that steel has been introduced for boiler making, we can not look forward to any further progress in the direction of obtaining a stronger material. Any effort to increase the strength of boilers should therefore be aimed at improving their shape and the disposal of material. This has been done conspicuously in the case of the various spherical, tubulous, and other so-called "unit," "segmental," or "sectional" boilers recently introduced.

The variety of shapes in which boilers are made, and in the attainment of which much ingenuity has been exercised, is due to the various ends they have been designed to meet. Among these may be mentioned strength, durability, smallness of bulk and weight, saving of labour and material, greater extent and efficiency of heating surface, improvement of circulation, prevention of smoke, economy of fuel, facility of examination, cleaning, and repairs.

A very early form of steam boiler was made spherical, of cast-iron, with the fire underneath.

Owing to its limited heating surface, it was soon replaced by vessels more favourable in this respect. A cylinder with flat bottom and curved top, having encircling flues, was soon adopted. To increase the strength of the bottom, it was found necessary to arch it inwards. With a view of obtaining still more heating surface, the vertical cylinder, in its turn, gave way to the horizontal oblong boiler. When wrought iron came into use, larger dimensions than had hitherto been employed were ventured upon, and the "Wagon" boiler first made by Watt, and so much in vogue, especially in Lancashire, thirty years ago, was at length produced. After passing through various modifications of form, designed with a view to increase the strength and amount of heating surface, this type is now rarely to be met with. Its tendency to change of shape, even in spite of elaborate staying, renders it unfit for the pressures now commonly employed.

With inclined sides and hemispherical top, the old vertical cylindrical boiler developed into the "Haystack," or "Balloon" boiler, of wrought-iron. This shape enjoyed a long run, and many specimens are still to be found in the Staffordshire district, some of them as large as 20 feet in diameter.

Owing to the want of heating surface, and liability to give way at the bottom, these boilers are disappearing before those of the present smaller cylindrical type, which, on account of their strength, are now mostly employed.

The simplest is that of the horizontal, externally-fired class, with flat or cambered, but most commonly with hemispherical, ends, called the "Egg-end" boiler. To increase the extent of heating surface, without adding to the bulk of the boiler, the internal flue was introduced, through which the hot gases passed on their way to the chimney.

In order to economise fuel, the fire was at last placed inside the tube, giving us the "Cornish" boiler, its name being taken from the district where it was first mainly employed. In consequence of the weakness of the large diameter of the single internal flue, when a large grate area was required, two flue tubes instead of one were adopted, which gives us the "Lancashire" boiler.

Numerous modifications of these two types are to be found. There is the "Breeches-flued" boiler, having the two furnace tubes combining into one long tube behind the bridge. The weak form of the combustion chamber or neck uniting the double furnace tubes with the single flue tube, which, however, admits of being strengthened, has been the source of frequent disasters. This defect, although not incurable, along with the diminished heating surface of the single tube, has led to the disuse of this boiler. There is also the "Butterly" boiler, with circular, or elliptical, internal flue. The concave arch at the front end, which was introduced to obtain a larger furnace, is of very weak shape, and renders this boiler unsuitable for high pressures. It is consequently passing out of date.

Another description is the multitubular boiler. The number of small tubes are introduced to gain more heating surface. The weak point of some specimens of this class is the combustion chamber, which requires strengthening by water tubes or other means.

In order to increase the amount of heating surface and the strength of the large internal flue tubes, as well as to improve the circulation of the water, small transverse water tubes have been added to the main tubes. The most conspicuous example of this modification of the "Lancashire" is the "Galloway" boiler, which has long found favour with steam users. The weak elliptical tube, when its form is not too

irregular, can be adequately strengthened by the vertical conical water tubes, and the whole made capable of sustaining as great a pressure as any of the internally-fired class enumerated.

It must, however, not be forgotten that the advantages just mentioned are gained by the sacrifice of simplicity, and they increase the difficulty of examination, cleaning, and repairs.

The "French or Elephant" boiler, with its two "bouilleurs" or heaters below connected by water tubes to the main shell above, though much used in France, has not come greatly into use in this country.

The various forms of vertical boilers with chimneys or flues passing through the steam space, may be described as modifications of the "Cornish" type placed on end. By altering the posture, however, many properties of the boiler are materially affected.

The vertical is the most protean of all the types of boilers, and, as a rule, the most wasteful of fuel. At the same time, their convenient shape renders them an invaluable adjunct to many branches of industry.

The "Rastrick" boiler, used extensively at iron works, is a vertical cylindrical boiler of large diameter, with one central longitudinal flue tube, communicating with two or more horizontal tubes through which the gases from the furnaces in connection pass to the central tube on their way to the chimney.

The "Locomotive" type is much used where little space is available, and, when the flat surfaces of the firebox are properly stayed, it can be made a very servicable and reliable boiler for high pressures and rapid generation of steam.

Some of the above-mentioned boilers have circulating and heating tubes added, such as Field's, Gadsby's and others, which add greatly to their steaming power, especially when new, and also, it must be admitted, to their complication.

Besides these cylindrical boilers, which are more or less of a simple type, there are the various kinds of so-called tubulous boilers now coming rapidly into use. These are, for the most part, modifications of the type first introduced by Woolf, consisting of numerous pipes, in which the steam is generated, communicating with a receiver above, in which it accumulates. The object aimed at in these boilers is safety from disastrous explosions and economy of fuel. For very high

pressures, some arrangement of this description will doubtless come largely into future use, but at present the design of more than one type appears to be in a transition state, and several very ugly, though not fatal, explosions have already occurred with some of these so-called inexplodable boilers.

CHAPTER II.

STRENGTH OF CYLINDER, SPHERE, AND FLAT SURFACES.

In analysing the various forms of boiler shells, they are found to resolve themselves into the cylinder, oval, sphere, cambered and flat surfaces.

THE CYLINDER.

According to the well known law of hydrostatics, the pressure of steam in a close vessel is exerted equally in all directions. In acting against the circumference of a cylinder, the pressure must therefore be regarded as radiating from the axis, and exerting a uniform tensional strain throughout the enclosing material. Its tendency to cause longitudinal rupture, or to rend the cylinder in lines parallel to its axis, may be considered as a force acting and reacting in opposite directions to divide the cylinder in two. As it must be exerted on equal areas in order that the action and reaction may be equal, this divellant force may be considered as the pressure exerted on the semi-circumference, and tending to rupture the cylinder in a plane drawn through the diameter. It follows, however, from the pressure acting equally in all directions, that the whole amount exerted on the semi-circumference is not equally effective in producing strain perpendicular to the diameter through which the cylinder may be assumed to rend.

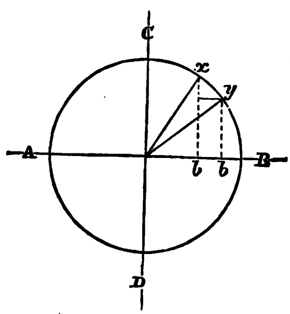
If we examine the force tending to cause rupture through the horizontal diameter A B. (fig. 1), we shall find the pressure is exerted directly upwards and downwards only along the vertical diameter C D. As we recede right and left from this line, the pressure is exerted diagonally with diminishing vertical effect, to produce tension at A. and B., until it vanishes altogether when we reach these points. The radial pressure

at any point may be resolved into two forces, the one vertical and the other horizontal. It is evident the latter has no tensional effect at A B. By taking the component vertical forces at an infinite number of points in the semi-circumference, it can be proved that their sum is equal to the full pressure exerted on a line equal in length to the diameter.

We may consider the cylinder as composed of a number of rings of a unit's length, say 1″, placed side by side, each of which resists the pressure independently of the rest.

Let A C B D represent such a ring, and let $P =$ pressure per square inch; $x\ y$, a very small portion of the circumference, and α the angle it makes with A B. The pressure exerted upon $x\ y$, along the radius which passes through its centre, will be $P \times x\ y$. If we decompose this force, the vertical component will be represented by $P \times x\ y \times \text{cosin.}\ a$; but $x\ y \times \cos.\ a$ is equal to the projection $b\ b$ of the arc $x\ y$ on the diameter A B. The vertical component will then be equal to $P \times b\ b$, and the sum of all the vertical components will be $P \times$ A B.

Fig. 1.



Hence the force tending to rupture the cylinder longitudinally is represented by multiplying the diameter by the pressure on each unit of surface. As this applies only to a cylinder of a unit's length, it is evident that the total amount of force tending to divide the cylinder in lines parallel to its axis is found by multiplying the above product by the length of the cylinder. The practical truth of this has been proved by experiment.

The retaining force opposed to this pressure is evidently the resistance of the material at the two opposite sides which bear the strain.

The manner in which the strain is borne by the material depends greatly on its thickness. When this is considerable, compared with the diameter, as in hydraulic presses and cannon, the inner layers of the material are more severely

taxed than those on the outside. This difference may be so great that the latter render no material assistance to the former. If we take two straight bars of the same material and section, but of different lengths, and submit them to the same tensile strain, they will be stretched, within certain limits, in proportion to their length. Suppose a bar 1 foot long is stretched $\frac{1}{10}$ inch by a given weight, then a similar bar 10 feet long would be elongated 1 inch by a similar weight, the extension being simply a factor of the length.* In a cylinder, say of 3 inches diameter and $2\frac{1}{2}$ inches thick, we may consider the thickness as divided into $\frac{1}{2}$-inch layers. The inner layer will have a mean length of about 11 inches, whilst the outer one will be about $23\frac{1}{2}$ inches long. Suppose the material just capable of bearing an elongation of $\frac{3}{10}$ inch per foot, then the inside layer would be damaged by an internal force that would expand the cylinder $\frac{1}{20}$ inch in diameter, whilst the outside layer would be stretched only to about one-half its tensile limit, being twice as long as the other. From this it may be seen how any increase in thickness beyond a certain degree may not add to the strength of the cylinder. The thickness of boiler shells and tubes is, however, so small compared with their diameter, that the tension from the radial pressure may be regarded as being uniformly distributed throughout the material, the whole section thus acting together to resist the strain.

The strength of the cylinder to resist transverse pressure is therefore proportionate to the thickness, and is represented by the tenacity or tensile strength of the material multiplied by the section on both sides, or twice the thickness multiplied by the length.

At the moment of rupture, this retaining force is equal to the bursting pressure.

Representing the pressure in lbs. per square inch by P, the diameter in inches by D, the length by L, the thickness of

* From the results of some tests of wrought-iron bars, Sir W. Fairbairn erroneously deduces a rule which makes it appear that the rate of elongation increases with the decrease of length. On approaching the breaking strain, a bar of good iron of uniform section always draws out considerably at and near the point of fracture. The amount of this local elongation, provided it be free to act, is independent of the length of the bar, and consequently, the ratio it bears to the total length increases as the length of the bar decreases. This fact has evidently been overlooked, and is apparently the cause of the error which has been generally accepted until indicated by Mr. Kirkaldy.

the material in inches by T, and its tensile strength by c we have at the point of rupture

$$P\,D\,L = 2\,T\,L\,c.$$

The factor L can be suppressed, and the equation stands—

$$P\,D = 2\,T\,c.$$

$$T = \frac{D\,P}{2\,c}.$$

In calculating the strength, it is usual to consider the length as unity. The correctness of this is here shown, the extra pressure due to increased length being balanced by a proportionate increase of material.

Although the length does not affect the strength of a cylindrical boiler with respect to the action of the internal pressure *per se*, we shall afterwards find that the length is an important condition when the expansion and contraction of the boiler on its seating are regarded as elements of weakness.

From the foregoing considerations, it is obvious that the strength of a cylindrical boiler to resist longitudinal rupture is in direct ratio to the thickness and tenacity of the material, and inversely as the diameter and the pressure. Speaking theoretically, and assuming the material of a cylinder to be of perfectly uniform strength throughout, it would be uniformly stretched, and its diameter increased by sufficient pressure. On reaching the bursting point it should give way all round its circumference at the same instant—in fact, be "blown to atoms." Of course this argument is entirely hypothetical. In practice there are always one or more lines of less resistance through which the fractures pass, leaving the rest of the material comparatively intact.

The tendency of the uniform radial pressure is to maintain the perfect circularity of the cylinder and to restore this form when it is departed from. Should the cylinder be somewhat oval, the two opposite sides at the extremities of the minor axis, having a greater pressure against them, will have a tendency to bulge outwards until their resistance becomes equal to that of the rest of the circumference.

This equilibrium of pressure and resistance can only be maintained when the circumference is perfectly circular.

In a shell of wrought iron, the perfect circularity cannot be obtained when the plates overlap longitudinally. In this case the deviation from the accurate circle is usually but trifling, and the weakness caused by the lap is rather to be attributed to the unequal distribution of the strain through the plates at the joint, than to the deviation from the circular form.

In a cylinder made with flat ends, the strength imparted by these renders it less liable to stretch at the extremities than at mid-length. Such a cylinder has thus a tendency, under internal pressure, to assume the form of a barrel.

Assuming the material to be sufficiently pliable, like india-rubber, and able to bear sufficient stretching, the sides would be further curved, and the spherical form be eventually attained by sufficiently increasing the pressure.

In very short cylinders, the ends play an important part in increasing the resistance to bursting longitudinally; and where the length does not exceed the diameter, the strength approaches that of a sphere. In practice, however, local weakness arising from various causes—such as corrosion of plates and rivet heads, flaws, &c.—may lead to failure, against which the aid from the ends cannot be counted upon.

Again, in oval shaped boilers, the end plates assist materially in maintaining the shape against the tendency to become circular under internal pressure. Since the aid lent by the ends diminishes as the distance from these increases, an oval boiler is most liable to change of form at mid length.

In consequence of their tendency to alteration of shape under pressure, it is almost impossible to give any rules for the strength of elliptical boilers, as their resistance varies with every change of shape, according to very complicated laws.

We have now to consider the strength of a cylinder to resist bursting in a plane perpendicular to its axis. The force tending to divide it transversely by separating two contiguous rings is evidently the amount of pressure exerted against the two ends which may be represented by the area of the cylinder multitiplied by the pressure per square unit of surface, or

$$P \times \frac{D^2 \pi}{4}.$$

The resistance opposed by the cylinder to this longitudinal force is measured by the tenacity of the material and the

amount brought into play to withstand the pressure. This is evidently the whole circular section of the cylinder, and as the strain acts directly, the whole tensile resistance of the material is exerted. The strength is therefore expressed by the area of the annular section multiplied by the tenacity of the material, or π T (T + D) c, when rupture is about to take place the bursting force and resistance are equal, therefore,

$$P \frac{D^2 \pi}{4} = \pi T (T + D) c,$$

$$P \frac{D}{4} = T \left(\frac{T}{D} + 1 \right) c,$$

neglecting $\frac{T}{D}$, which is usually small, we get

$$T = \frac{P D}{4 c}.$$

As the formula for the longitudinal strength is

$$T = \frac{P D}{2 c},$$

on comparing these two formulæ we see that with the same internal pressure, diameter, and thickness of shell, a cylindrical boiler is twice as strong transversely as longitudinally.

It must not, however, be concluded from this that a cylindrical boiler is always more liable to burst from longitudinal than from transverse weakness. Many explosions occur from the latter source, the cause of which we shall consider fully when treating of the wear and tear of boilers.

It may be here observed that in most experiments on the tenacity of metals, the material is not subjected to any lateral strain, whereas in a cylinder under internal pressure the metal is strained both longitudinally and transversely at the same time. The question then arises whether this circumstance has any influence on the strength of the material, and whether we are justified in taking the direct tensile strength in calculating the resistance of a cylinder. This question has long been set

at rest by the direct experiments of Navier on wrought-iron spheres, as well as by long experience with boilers at work, which show conclusively that the strength of the metal is not affected when it is strained simultaneously in all directions, and the resistance is the same as when the stretching is exerted in one direction only.

A table of the strength of wrought-iron boiler shells of different dimensions is given at page 311.

A cylinder or tube in resisting external fluid pressure may be considered as an arch. As the pressure is exerted equally all round the circumference, the figure, in order to resist it uniformly, should be similar to itself all round, and therefore a circle. Speaking theoretically, if the circular form be perfect, and the resistance of the material quite uniform throughout, the tendency of the pressure will be to diminish the diameter by compression. On its compressive strength being exceeded, it will depend on the nature of the material and other conditions, whether the thickness of the cylinder will increase in proportion as the diameter is diminished, or whether the material will also be forced out at right angles to the pressure against it, thus lengthening the cylinder.

The force against any two opposite sides tending to close them together by forcing out the rest of the circumference at right angles will be exactly balanced by the resisting force exerted here, and the whole pressure and resistance will be in equilibrio at all points of the circumference.

Should, however, the figure and material of the cylinder not be perfect, which is always the case in practice, and more especially in tubes of considerable diameter compared with the thickness, the equilibrium is destroyed, and the tendency of external pressure is to aggravate any deviation from the circular form and consequently to cause collapse by excessive pressure. The collapsed cylinder may assume various shapes, depending upon the original form and want of uniformity of strength in the material.

It has been shown that the strength of a cylinder to resist internal pressure was not affected by its length, when we disregard the extra strength imparted by the ends. But it is otherwise with a cylinder exposed to external pressure, its power of resistance being materially influenced by its length.

The important part played by the length of a cylinder in resisting external pressure is not generally understood; in fact, until a few years ago, it was altogether unknown, and was only

ascertained by experiment. When we bear in mind that the tendency of internal pressure is to rectify any deviation from the circular form, whereas external pressure tends to aggravate any distortion, it can be clearly seen where the analogy of the two cases fails in considering the effect of the length upon the power of resistance. Were the cylinder under external pressure theoretically uniform both with respect to material and shape, the length would not affect its power of resistance if we disregard any additional strength lent by end attachments, which, however, in this case would exercise only a limited influence. Such a theoretical cylinder is self-supporting with respect to the pressure. But on the least departure from the shape on which this self-supporting principle depends, it is evident that the assistance of the end attachment is very material in maintaining the form of the tube.

The value of this assistance will decrease as the distance from the ends increases. Hence the surface of an irregular cylinder or oval tube may be regarded as a beam supported at both ends, having the load uniformly distributed. The strength of the tube must therefore be dependent on the laws which govern the strength of beams. Any strip of a unit's width taken for estimating the strength must, however, be regarded as a beam of undefined section, in consequence of the strength imparted by the arched form, and the material on either side.

The rule usually employed for the strength of cylindrical tubes, subject to external pressure, is deduced from the results of a valuable series of experiments conducted by Sir W. Fairbairn, and given in the second series of his "Useful Information for Engineers." It is as follows :—

$$P = 806{,}300 \times \frac{k^{2 \cdot 19}}{L\,D} \quad \ldots\ldots (1)$$

a convenient modification being

$$P = 33 \cdot 61 \times \frac{(100\,k)^{2 \cdot 19}}{L\,D} \quad \ldots\ldots (2)$$

For facility of calculation it may be written,

$$\text{Log. } P = 1 \cdot 5265 + 2 \cdot 19 \text{ log. } 100\,k - \text{log. } L\,D.$$

Here P = collapsing pressure per square inch.
k = thickness of tube in inches.
L = length of tube in feet.
D = diameter of tube in inches.

The following numbers usually required for $K^{2 \cdot 19}$ may be seful :—

$$\left(\frac{3}{16}\right)^{2 \cdot 19} = 0 \cdot 02558.$$

$$\left(\frac{7}{32}\right)^{2 \cdot 19} = 0 \cdot 03585.$$

$$\left(\frac{1}{4}\right)^{2 \cdot 19} = 0 \cdot 04803.$$

$$\left(\frac{9}{32}\right)^{2 \cdot 19} = 0 \cdot 06216.$$

$$\left(\frac{5}{16}\right)^{2 \cdot 19} = 0 \cdot 07829.$$

$$\left(\frac{11}{32}\right)^{2 \cdot 19} = 0 \cdot 09646.$$

$$\left(\frac{3}{8}\right)^{2 \cdot 19} = 0 \cdot 11671.$$

$$\left(\frac{13}{32}\right)^{2 \cdot 19} = 0 \cdot 13908.$$

$$\left(\frac{7}{16}\right)^{2 \cdot 19} = 0 \cdot 16358.$$

$$\left(\frac{15}{32}\right)^{2 \cdot 19} = 0 \cdot 19027.$$

$$\left(\frac{1}{2}\right)^{2 \cdot 19} = 0 \cdot 21915.$$

$$\left(\frac{17}{32}\right)^{2 \cdot 19} = 0 \cdot 25027.$$

$$\left(\frac{9}{16}\right)^{2 \cdot 19} = 0 \cdot 28364.$$

$$\left(\frac{5}{8}\right)^{2 \cdot 19} = 0 \cdot 35725.$$

Instead of the 2·19 power, the square of the thickness is sually taken *as being* sufficiently correct for practice. This,

it may be remarked, gives a higher collapsing pressure, the thickness being always in fractions of an inch for boiler tubes. For ordinary lap-jointed tubes, the square of the thickness gives a result nearer the collapsing pressure, found by experience with boilers in use. It must, however, be observed that the experiments referred to were made with tubes of a length not exceeding 15 diameters. Theoretically speaking, when this proportion of length to diameter is exceeded, the collapsing pressure given by the rule is too high. This objection applies, practically, to small solid-rolled wrought-iron and brass tubes. But when the tubes are made up of courses of plates, the lap or butt joints at the ring seams become an element of strength, the tube being virtually divided by these into so many short lengths. These transverse joints only require to be made sufficiently strong, in order to render the distance between them the actual length by which the collapsing strength is to be measured. The most important result of this fact is the power it gives us of reducing the thickness of the plates, without diminishing the diameter or total length of the tube.

Bearing in mind that the strength is impaired by any deviation from the true circle, it is obvious that the employment of the lap joint for the longitudinal seams must have an injurious effect on the resisting power of a tube.

In the experiments referred to, two tubes were tested, 37 inches long, 9″ diameter, and $\frac{1}{8}''$ thick, one having single riveted lap joints, and the other butt joints, with a single strip at the longitudinal seams. The results showed a loss of more than one third in strength of the former, as compared with the latter, the ratio being 7 : 10 nearly. We then see how seriously the collapsing strength of even a short tube, only four times the diameter in length, is impaired by a departure of $\frac{1}{36}$th of the diameter from the circular form, and the necessity of welding or butting the plates when great strength is required. In practice, however, the longitudinal seams of furnace tubes are usually arranged to break joint in successive courses of plates. This arrangement, together with the increase of strength due to the lap at the ring seams, appears from experience to bring the collapsing strength fully up to that given by the formula,

$$P = \frac{806,300\ k^2}{L\ D} \quad \ldots\ldots (3)$$

in cases where the circularity is not departed from to a greater

extent than twice the thickness of the plates composing the tube.

When the plates are arranged so that their length in a longitudinal direction is short and the longitudinal seams break joint, the weakness of the irregular cylinder is not so likely to be in line, and the tube is therefore stronger than when the plates are narrow and arranged lengthwise along the tube with the seams in line from end to end. For this reason the latter arrangement should not be employed unless the tube has a large margin of strength, and in such a case it is better in calculating the collapsing pressure to use the 2·19 power of the thickness of plate.

The difficulty of maintaining the cylindrical form increases with the diminution of the ratio which the diameter of the tube bears to the thickness. This is not taken into account in the formula; but experience proves that it need not be regarded when the diameter does not exceed 150 times the thickness.

In order to show that the rule for the strength deduced from his experiments on tubes of limited size holds good for tubes of greater length and diameter, Fairbairn records some experiments on a large scale with two boilers 35 feet and 25 feet long, the tubes being in both cases 3′ 6″ diameter, and composed of $\frac{3}{8}$ plates. The 35-foot tube collapsed with 97 lbs., and the 25-foot tube with 127 lbs. per square inch. By formula (1), these pressures should have been respectively 64 lbs. and 89 lbs. By using the square of the thickness as in formula (3), these figures would stand 78 lbs. and 109 lbs., which accords more closely with the results of the experiments.

In actual work, the form of a horizontal furnace tube is probably somewhat distorted by the heat, which is greater on the top than on the bottom. The effect of expansion by heat on a loaded arch resting on its abutments will be to increase its height; but it will depend upon the original shape of an ordinary cylindrical tube pressed externally all round its circumference, whether the effect of the heat acting on its crown will cause an increase of diameter vertically or horizontally. The application of heat to the flattened crown of a slightly oval furnace tube would tend to restore the circular form were the tube not under pressure. But the effect will be altered when it is pressed all round. The heat will now farther aid the pressure to increase the distortion by forcing out the sides. Should, on the other hand, the flatness be in the sides, the heat will *tend still farther* to increase the height of the crown,

and so again add to the distortion. The question then arises, whether the direction of the elliptical form has any influence on the strength of a horizontal furnace tube. There can be little doubt that the tube is considerably weaker when the smaller diameter is vertical than when it is lateral, probably owing to the fact, that the resistance to longitudinal expansion offered by the end plates tends to flatten the crown, at the same time the heat renders the plates most pliable and susceptible to the influence of the pressure when the crown is flattened. In addition to this, the pressure due to the displacement of the water being greatest on the under side, its effects will be more felt when the tube is flattened vertically, than when the flattening occurs laterally.

In elliptical tubes the resistance to flattening varies inversely as the largest radius of the curvature. The weakness of such tubes was clearly shown in Fairbairn's experiments. A tube 14″ × $10\frac{1}{4}$″ diameter, 5 feet long and $\frac{1}{8}$ inch thick, collapsed with 6·5 lbs. pressure, another tube $20\frac{3}{4}$ inch × $15\frac{1}{2}$ inch diameter, 5 feet 1 inch long and $\frac{1}{4}$ inch thick collapsed at $127\frac{1}{2}$ lbs. per square inch. These results show that the general formula applies sufficiently correctly to elliptical tubes by substituting for D the diameter of the larger circle of curvature in the tube, or $D = \frac{2\,L^2}{S}$ where L and S are respectively the major and minor axes of the ellipse.

The comparative weakness of cylindrical tubes under external pressure will be seen from what has been stated above, and the formulæ given are sufficient data to enable us to find an expression for the maximum length of a cylindrical tube having a collapsing strength equal to the bursting strength of any given diameter of boiler.

Taking the strength of a single riveted joint as 26,340 lbs. $= c$; $p =$ internal or bursting pressure; $K =$ thickness; $D =$ diameter and inches; $L =$ length in feet, we have

$$p = \frac{52{,}680\,K}{D};$$

where $P =$ external or collapsing pressure, we have

$$P = \frac{806{,}300 \times K^2}{D\,L}.$$

Calling R the ratio of boiler tube diameter to shell diameter, we get,

$$\frac{p}{P} = \frac{L}{15{\cdot}3 \times K} \times R$$

when $P = p$, we have

$$L = \frac{15{\cdot}3 \times K}{R}.$$

Taking a Cornish boiler of $\frac{3}{8}$ plates, having a tube one-half the diameter of shell :

$$L = 15{\cdot}3 \times {\cdot}375 \times 2 = 11{\cdot}47 \text{ feet.}$$

Thus we see that the boiler in this case should not exceed $11\frac{1}{2}$ feet in length to be equally strong in shell and tube. As the former will not be impaired by lengthening, we have only to make the latter in $11\frac{1}{2}$ feet lengths, in order to preserve an equality of strength in tube and shell, having their diameters in the ratio of 1 : 2, whatever length the boiler may be.

A table of collapsing pressures is given on page 314.

THE SPHERE.

From what has already been stated concerning the action of steam pressure in a close vessel, it will readily be seen that in order to resist the pressure throughout its whole surface in an equal manner, the containing vessel must be similar to itself in all its parts. This property is possessed only by the sphere, which renders it the best of all forms for resisting internal pressure.

To the sphere also belongs the property of containing the greatest volume within a given amount of surface, and owing to this the internal fluid pressure tends to make any containing surface assume the spherical form.

By employing a modification of the reasoning we used in demonstrating that the internal pressure tending to rupture a cylinder in lines parallel to its axis is to be measured by the diameter, and not by the semi-circumference of the cylinder, we should find that the internal pressure tends to burst a sphere through the largest plane we can draw through it, and is

to be measured by the area of its diameter, and not by that of the hemisphere. The divellent force can therefore be represented by the formula,

$$P \times \frac{D^2 \pi}{4}.$$

The resistance opposed to this force is that due to the tensile strength of the material multiplied by the area of its section in the circumference of the sphere and can be expressed by

$$\pi T (T + D) c;$$

when rupture is about to take place these two formulæ must be equal, therefore

$$\frac{P D^2 \pi}{4} = \pi T (T + D) c,$$

whence we get, as at page 12

$$T = \frac{P D}{4 c},$$

the same expression that we obtained for the transverse strength of a cylinder. The sphere therefore is twice as strong as a cylinder of the same thickness and diameter is longitudinally.

The relative strengths of the sphere and cylinder may be considered in another manner :—taking the diameter of a sphere as unity, its circumference is 3·14159, and area 0·7854. A cylinder of the same diameter and equal sectional area must be ·7854 long. The sum of the two sides is, therefore, 1·5708, or half the circumference of the sphere, and therefore only half as strong. This, of course, leaves out of consideration the strength imparted by the ends which, however, cannot be counted upon when the cylinder is long in proportion to the diameter.

In a cylindrical boiler of uniform thickness throughout, with hemispherical ends, the strength of these, being portions of a sphere of the same diameter as the boiler, is evidently equal to that of a cylinder of equal diameter to resist transverse rupture, and twice as great as the strength in a longitudinal direction. It is clear, then, that the ends of this form are unnecessarily *strong compared* with the cylindrical portion of the boiler in its

power to resist longitudinal rupture, by which the strength of the boiler is measured.

By making the ends cambered to a radius equal to the diameter of the cylinder, their strength will be equal to that of the shell, as they will then be portions of a sphere having a diameter double that of the cylindrical barrel. By this means we employ the least amount of material consistent with adequate strength.

In diminishing the camber of the ends, the amount of material to resist being torn asunder decreases less rapidly than the tensile force exerted upon it. The tensile strength of the ends is therefore increased by flattening, although their resistance to bulging is reduced. Their efficiency in strengthening the cylindrical portion of the barrel will be farther increased as the amount of camber is reduced. But as the cylinder should be sufficiently strong of itself, the ends are not required to aid it, and should be designed simply with a view to resist bulging outwards by the pressure.

The manner in which a cambered end plate resists bulging is, perhaps, best understood by regarding it as a portion of the sphere to which it belongs. The radial pressure in this case tends to maintain the form of the segment as well as if it were a whole sphere, and the plate will fail by bulging only on exceeding what would be the tensile strength of the material in the sphere. The amount of pressure sufficient to accomplish this may be safely taken as that which would burst the sphere of which the segment forms a part. It follows, therefore, that the relative strengths of a dished or cambered end and a cylindrical barrel are found by comparing the radius of the camber with the diameter of the cylinder.

The sphere possesses one property for a boiler, and likewise also the cylinder, yet in a less degree, not often noticed, but the value of which cannot be over estimated, viz., the facility with which it expands on the application of heat to one portion of the surface, and with which it accommodates itself alike to the heat and the pressure without throwing any severe thrust or strain to cause leakage or fracture on the surrounding parts that may be comparatively cool.

FLAT SURFACES.

Advantage is usually taken of the self-supporting property of the cylinder and sphere in constructing parts of boilers

having these forms, which enables them in most cases to be made sufficiently strong, without the aid of stays, ties, or other support. But the absence of this self-sustaining property in flat surfaces necessitates their being strengthened by stays or other means.

Even where a flat or slightly dished surface possesses sufficient strength to resist actual rupture, it is yet, generally speaking, necessary to apply stays, to provide against undue deflection or distortion, which is liable to take place to an inconvenient degree, or to result in grooving long before the strength of the plates or their attachments is seriously taxed.

The theoretical investigation of the strength of plane surfaces, such as the flat end of a cylinder, is attended with considerable difficulty, and cannot be satisfactorily pursued without the aid of the higher mathematics.

The formula given by Professor Rankine for the strength of a flat circular plate of the diameter D, and supported all round the edge with the load uniformly distributed, is equivalent to the following expression, where

P = Bursting pressure per square inch in lbs.,
D = diameter of cylinder in inches,
t = thickness of end plate in inches,
c = breaking weight of the material in lbs.,

$$\frac{P\,D^2\,\pi D}{24\pi} = \frac{c\,D\,t^2}{6}.$$

$$\text{Whence } t = \sqrt{\frac{D}{2} \times \frac{P\,D}{2\,c}}.$$

Now, taking T as the thickness of the cylinder that resists longitudinal rupture under the same conditions of pressure as the flat end plate, we had above,

$$T = \frac{P\,D}{2\,c},$$

$$\text{Therefore } t = \sqrt{\frac{D}{2} \times T}.$$

We have here assumed the factor c to be the same quantity

for a tensile and a cross breaking strain, which we can safely do in such a case as we are considering.

The last formula shows the monstrous thickness it would be required to give the unstayed flat end of a cylindrical boiler in order to make it equally strong with the shell. For a boiler only 3 feet diameter and of $\frac{3}{8}''$ plates, single riveted, the solid end plate would require to be about 2" thick to comply with this condition. It is obvious, therefore, that for boilers of ordinary diameter, the flat ends, if of moderate thickness, require to be well strengthened by stays or ribs.

When longitudinal tie rods are employed as stays, the L or T irons securing them to the end plates are usually arranged horizontally. Gusset stays are usually arranged in planes radiating from the axis of the boiler. The best arrangement for T iron stiffening ribs will depend upon the design of the boiler. Each series of longitudinal stays bears the pressure against a rectangular portion of the flat end, and each gusset stay sustains the pressure against a sector of the circular area.

The flat surface between two series of stays may be considered as a rectangular beam, fixed at the ends, and uniformly loaded, and its strength calculated accordingly, the tendency of the pressure being to split the plate up the middle between the stays.

If we disregard the strength imparted by the end attachments, we may employ the usual formula for the strength of such beams, as follows :—

Where w = distributed breaking weight,
l = width of plate between side supports, in inches,
b = length of plate in inches,
d = thickness of plate,
c = modulus of rupture = 54,000 for wrought iron,
P = pressure in lbs. per square inch.

$$\frac{w\,l}{2} = c\,b\,d^2$$

$$\text{As } w = \text{P}\,l\,b$$

$$\text{We have } \frac{\text{P}\,l^2}{2} = c\,d^2.$$

The same formula may be used for estimating the strength of flat surfaces stayed by bolts, such as the sides of locomotive fire boxes, &c. Tables for the strength of stayed surfaces, calculated by this formula, are given in the chapter on "Construction."

CHAPTER III.

PROPERTIES AND CHARACTER OF BOILER MATERIALS.

CAST IRON.

CAST IRON is the name given to a material, whose physical properties may vary through a wide range of brittleness, hardness, and tenacity. It is sometimes found so brittle as to be almost incapable of being worked; at other times it is found, or rather was once to be found, exhibiting such toughness as to render it capable of being chipped by a chisel or bent by pressure equally as well as many inferior specimens of material now sold as wrought iron.

That cast-iron is unsuited for boiler making no farther evidence is required than the fact of its almost total rejection for this purpose after having had a fair trial. Yet, despite the unanimous acceptance of its condemnation, it must be allowed that it possesses advantages which, considered in the abstract, appear to render it the most eligible of the scanty stock of materials from which the boiler-maker has to make his selection.

Its low first cost, combined with facilities of working, place it in the first rank of constructive materials, and probably led to its being largely used for boiler making in the early days of steam engineering. In its power to resist wasting on exposure to the action of flame in a boiler furnace, or to the atmosphere when in contact with moisture, it is superior, *if of suitable quality*, to wrought iron, and also in its power of resisting the corrosive action of the feed water and of acids found in the products of combustion.

Inferior strength alone can scarcely be regarded as a bar to its employment in vessels for resisting pressure, when we consider that the strength of a structure like a steam boiler depends as much on its size and form as on the actual strength *of the* material. The employment of cast iron to bear great

pressures in our water mains, hydraulic presses, and cannon, proves that low tensile strength alone would not prevent its adoption for boiler making, as any disadvantage on that score would be outweighed by its constructive and other advantages.

As an instance that the breaking strength alone of a material is no test of its eligibility for sustaining high steam pressures, it may be mentioned that the employment of copper for flat surfaces in locomotive fire boxes meets with great favour in this country, in spite of its being in that form the least adapted of all boiler making materials for resisting pressure. Everything in this instance is sacrificed to malleability, ductility, and high thermal conducting power. By proportioning their diameters in the ratio of their tensile strength, cast and wrought iron cylinders or spheres can be made of equal strength, with the same thickness of metal. The difference between the strengths of cast and wrought iron vessels in the form best adapted to the constructive properties of each, is by no means so great as it may at first sight appear. With single riveting we can not take the strength of ordinary plates at more than 12 tons per square inch at the joints. The tensile strength of cast iron being about 6 tons, and having no seams or other necessary loss of strength, it follows that a sphere of cast iron is equally as strong as a cylinder of wrought iron single riveted of the same diameter and thickness. But when both materials are used in the same form to resist tensile strain, the greater thickness that must be given to cast iron, in consequence of its inferior tenacity, raises its cost to that of wrought iron, the price o :the materials being in proportion to their cohesive strength in the finished structure.

In seeking, then, for some other cause than the inferior tenacity to account for the rejection of cast iron, in spite of its numerous advantages, we shall find that the strong feeling which, notwithstanding strenuous individual efforts to remove it, exists against its employment for boiler purposes, must be ascribed to its brittle and treacherous nature.

Besides the uncertainty of strength caused by defective moulding, and the unequal tension on different parts of the same piece, usually ascribed to obscure causes in the process of casting and cooling, a very slight hidden or surface defect, in an otherwise sound casting, is sometimes sufficient to lead to a sudden and *extensive fracture.* Moreover, cast iron, in breaking, seldom

gives warning by indication of weakness, such as usually precedes the failure of wrought-iron structures. The risk attending its use in large masses, in consequence of its treacherous nature, is greatly aggravated when the material is subject to the strains caused by sudden and unequal expansion and contraction consequent upon the sudden and extreme variations of temperature it is exposed to when employed for vessels to raise steam in. To this cause must the rejection of cast iron be ascribed, together with the dread of the disastrous effects that would probably result from the explosion of a cast-iron boiler containing a large body of highly heated water, which would probably be similar to those resulting from the bursting of an explosive shell. When wrought-iron boilers explode, large masses of plate usually hold together, and tend to mitigate the effects of the explosion.

It is only when these two causes act conjointly, viz., (1), untrustworthiness of the material when exposed to trying trains, and (2), dread of explosion when the material contains a large body of highly-heated water, that cast iron is deemed unsuitable for boiler making, as may be seen from the following considerations :—

1. In order to mitigate the disastrous effect that would ensue from the sudden liberation of a considerable volume of water at a very high temperature, on the bursting of a large vessel, various types of cast-iron "sectional" boilers have been introduced. Being composed of many small pieces, either spherical or cylindrical, it is held by the advocates of these boilers that in the event of one portion suddenly giving way the explosion would be confined to a single segment, and its effects would be insignificant, as the hot steam and water would be gradually discharged. It is for this reason that cast-iron boilers of this class, although subject to the same variations of temperature as ordinary steam generators, are employed without anxiety. It may be remarked that the unequal straining, and consequent liability to fracture, is much less in small than in large vessels.

2. There are some cast-iron boilers, with wrought-iron internal flues, whose rupture would suddenly liberate a sufficiently large quantity of heated water to cause a very disastrous explosion ; yet these are worked without fear of bursting, as they are not exposed to sudden variations of temperature, the furnaces being in the internal tubes. In such boilers, however, there will be a marked difference of temperature between the top of the shell and the bottom, especially when starting the boiler afresh

after filling with cold water, which must strain them considerably.

3. When not entering into the construction of the boiler itself, cast iron is almost invariably used, except with marine boilers, for pipes to carry the steam to the engine cylinders at the full boiler pressure. These cylinders being of cast iron are very often of larger diameter than boilers it would rightly be deemed foolhardy to make of the same material, and to work at the same pressure. This apparent inconsistency admits of ready explanation. In the engine cylinder the heat is, comparatively speaking, uniformly distributed. There are wanting the fire and currents of cold air through the furnace-doors and bars to render the material untrustworthy; and when the cylinder does happen to burst—by no means a rare occurrence—the quantity of water present, although often the actual cause of fracture, is so small, and at so low a temperature, as to render the effects of the bursting comparatively harmless under ordinary circumstances.

A large cylindrical vessel placed horizontally, with a fierce fire acting on the under side, and but moderately heated above, would be severely strained by the unequal expansion. A brittle and unyielding substance like cast iron would certainly not stand such a test without injury.

In order to bear a high temperature without fear of fracture a large cylinder of cast iron should be heated equally all round its circumference, yet not necessarily along its entire length if the application and withdrawal of heat be gradual, and if the vessel be free to expand and contract uniformly. Such a cylinder is therefore less adapted for a horizontal than for a vertical position. The vertical arrangement for large cast-iron cylindrical boilers with external firing was formerly used. Its abandonment was probably due to the small amount of heating surface this arrangement afforded. In order to increase the extent of this surface the obvious method is to diminish the diameter and increase the number of cylinders to receive the heat, producing at the same time a stronger and more efficient boiler. This has recently been done, and boilers composed of vertical cast-iron pipes 4 inches or 6 inches in diameter are at present employed and worked at pressures as high as 80 lbs. or 90 lbs.

The difficulty, or rather, inexpediency of repairing the vessel by patching is another reason for making cast-iron boilers and similar *structures in small* segments, the replacing of a defective

portion being by this means attended with the least sacrifice of material.

It is sometimes asserted that cast iron does not become covered with incrustation so readily as wrought iron or copper. However true this may be in the case of cast-iron spheres, where the coating, if sufficiently thick and brittle, may be cracked off by the inequality of expansion between itself and the metal, it is certainly not the case with respect to cast-iron pipes, which become thickly coated over with a scale that defies removal when bad feed-water is used.

Seeing that the prevailing types of wrought-iron boilers having large cylindrical shells are such as we could not venture to make of cast iron, and that, at the same time, cast iron can be safely used in certain other arrangements, the question may arise whether the prevailing type of boiler is the cause or the effect of the rejection of cast iron in favour of wrought iron for boiler making. If, on the one hand, facilities of cleaning, and examination, and repairs, as well as an economical fuel consumption, render the present boiler of large section superior to any other form, the abandonment of cast iron would certainly follow. But if, on the other hand, the untrustworthy nature or other adverse property of cast iron in any form whatever resulted in its rejection in favour of wrought iron, the effect would be, without further consideration of economy, the adoption of the prevailing types as being the most suitable for constructing of wrought-iron plates.

There can be little doubt the latter conclusion is the correct one. The difficulty of making good steam-tight joints when wrought iron first came largely into use for boiler making, would of itself preclude the use of cast iron in small segments, the only shape in which it can be safely employed.

At the present day the increased facilities for making strong seamless wrought-iron tubes of various sizes will exercise considerable influence on the design of the boiler of the future, and probably, to some extent, indirectly lead the way to the larger introduction of cast-iron segmental boilers.

Of late years the employment of cast iron in connection with boilers has been chiefly confined to the larger descriptions of mountings and seatings, and to steam domes and chambers. For the former it will doubtless long continue to be used, as it here possesses advantages superior to all the other materials, *except* brass, whose price, however, will prevent it from ever *g largely used for* land boilers.

In the employment of cast iron for boiler mountings care should be taken that it is not placed where sudden variations of temperature are likely to occur. When used for steam domes and pipes of large diameter a large margin of safety should be provided, and castings of these descriptions should always be carefully tested by hydraulic pressure, to guard against insidious defects and errors that but too frequently occur in the foundry, and which it is impossible to detect by any ordinary optic or acoustic tests.

No better example of the treacherous nature of sound cast iron can be given than the fatal explosions of steam stop-valves that have occurred in frosty weather through opening the valve and allowing the steam to enter suddenly from the upper portion into the lower containing water at a low temperature, which has caused the cast-iron valve casing to crack like glass, from the unequal expansion, and to be violently blown about, with as low a pressure as 10 lbs. above the atmosphere.

The above is one reason, amongst others, why a range of steam pipes should always be arranged or provided with means to drain the water from condensation away from the end where the steam enters.

When a certain amount of strength is required in a casting, it is usual to specify the mixtures by giving the names and proportions of the pig-iron to be used. The most satisfactory course, however, is to specify the tests the metal must be capable of standing, and allow the founder to choose his own mixtures, which will vary considerably in different districts.

With regard to judging the quality of the iron by an inspection of the fracture, this is by no means a simple matter, as the appearance of good iron is found to vary widely in different localities. Such defects, however, as honeycombing and chills, arising from want of care or skill in moulding and running the metal, and the presence of particles of graphite, showing a defect in the mixing, are unmistakable.

The strongest irons are of a light grey colour, without much lustre, close grained, and sometimes mottled. Others exhibit a somewhat fibrous or jagged surface, of light colour, and when closely examined are found to be close grained. On the other hand, a blackish or bluish grey, with large loose grains, and having generally a shiny appearance, indicates inferior tenacity.

COPPER.

The superiority of copper for boiler making, when compared with wrought iron, consists in the uniformity and homogeneity of its texture, freedom from lamination and blisters, and in its general trustworthy character when well selected ; in its great resistance to oxydising influences and the corrosive action of many descriptions of feed water ; in the manner in which it resists the tenacious adhesion of most kinds of incrustation ; in its great ductility and malleability, which render it capable of being worked with great ease and of bearing sudden as well as oft-repeated racking strains : in its being a better conductor of heat, which not only tends to give it a higher evaporative power under favourable circumstances, but also enables it to last longer when exposed to a fierce wasting heat in a boiler furnace.

Before the rolling of sound wrought-iron plates in large quantities was attended with the certainty of recent years, copper was rightly considered the most eligible and trustworthy material for steam boiler shells, and was so used to some extent, but owing to its high price and inferior tensile strength its employment for this purpose has long been abandoned in favour of wrought iron and steel. But for its high price, its non-liability to suffer from the action of some descriptions of corrosive feed water and consequent durability would, doubtless, in many cases outweigh any objections on the score of inferior tenacity. In judging of the comparative cost, it must not be forgotten that old copper will average a price of £66 per ton, whilst old iron will not fetch more than £5 on an average, being respectively two-thirds and one-third their price when new.

The softness of copper when used in a comparatively pure state has been found to render it unfit to resist the abrasion it is subject to when used for the tubes of coal and coke-burning boilers, for which purpose its facility of manufacture at one time especially recommended it.

The use of copper in boiler construction is now almost restricted to the fire-boxes and stays of locomotive boilers. Notwithstanding its weakness to resist pressure when employed in a flat surface, especially in a furnace, its high heat-conducting power and ductility are considered, in this country at least, to render it more suitable than wrought iron or steel, for *bearing the intense* heat and unequal strains of a locomotive

furnace. In America, and, to a great extent, on the continent, iron plates of half the thickness are successfully used instead.

There can be little doubt that the quality of copper has deteriorated of late years, much of it being now of a comparatively hard and brittle quality.

One adverse property possessed by copper, in which it presents a marked contrast to iron and steel, is the great diminution of its tensile and transverse strengths at moderately high temperatures. From numerous experiments undertaken by the Franklin Institute in America, it was found that, taking a temperature of 32° Fahrenheit as a standard, every increment of heat caused a diminution of tenacity in copper plates. Thus a cold strip capable of carrying 10,000 lbs. was only capable of carrying 7,500 lbs. when heated to a temperature of 500°, and at 1200°, a visible red heat in daylight, no more than about a tenth part of the strength remained.

Table of Diminution of Strength of Copper Boiler Plates when heated. Their standard strength at 32° being 32,800 lbs. per square inch.

	Temperature above 32°.	Diminution of Strength.		Temperature above 32°.	Diminution of Strength.
1	90°	0·0175	9	660°	0·3425
2	180	0·0540	10	769	0·4398
3	270	0·0926	11	812	0·4944
4	360	0·1513	12	880	0·5581
5	456	0·2046	13	989	0·6691
6	460	0·2133	14	1000	0·6741
7	513	0·2446	15	1200	0·8861
8	532	0·2558	16	1300	1·000

From the above it is seen that in being heated from the freezing point to the boiling point of water, copper loses 5 per cent. of its strength; at 550° it loses about one quarter of its strength, and at 1332° loses all its tenacity, becoming a viscid, granular, soft, incoherent mass, although it does not actually melt until it reaches nearly 2000°.

WROUGHT IRON.

Wrought iron is the material which, for the last forty years, has been by far the most extensively used for boiler making. The reason for this is not far to seek, and has been partially indicated in discussing the constructive merits of cast iron. The great tensile strength of good wrought iron, together with its ductility, power of bearing sudden and trying strains, and general trustworthy nature, its moderate facilities of working, the ease with which it can be welded, riveted, patched or mended, its moderate first cast compared with that of copper, are all important advantages which contribute to its value and the deservedly high esteem in which it is held for the construction of vessels exposed to the ever varying and trying strains that steam boilers have necessarily to bear.

As it is mainly in the form of plates that this material enters largely into the construction of the prevailing types of boilers, we will at present confine ourselves to it in this form, leaving the not less important consideration of its strength and behaviour as bar iron when used for stays and angle irons to be subsequently dealt with.

Wrought-iron plates, it is well known, are manufactured of different qualities, ranging from the badly refined, coarse, brittle and uncertain material sometimes sold as ship plate, through various medium qualities to the valuable "Best Yorkshire" plates, so justly prized above all others for boiler making.

In consequence of competition and lowering of prices we often find boilers made of inferior material that scarcely deserves the name of wrought iron, the result being annoyance, pecuniary loss in the long run, and frequently fatal disaster. It would, indeed, be well if it were unnecessary to say that plates of ship quality should never enter into the construction of boilers, on account of the risk to life and property that always attends their use.

For a long time the "Best Best" and "Treble Best" Staffordshire plates have deservedly been in great request for boiler making. Formerly, when the production of these plates was confined to the locality whence they derive their name, and to the surrounding district, they could be generally trusted as being of good ductile iron, and well adapted for all the processes in boiler making. Although Staffordshire plates of excellent and reliable quality are still abundantly manufactured, those of *so-called* "*Staffordshire* quality" cannot at the present time be

so generally relied upon, and care should be exercised in their selection. They are made in different parts of the country, their properties depending in great measure upon the nature of the ores and fuel found in the districts where they are produced.

Experience has shown that the plates from mills where only superior qualities are made, are more trustworthy than those turned out by the mills where all classes of plates are made, from the so-called "Low Moor quality" down to the veriest ship plates. Instances of apparent caprice are not uncommon where the inferior brands prove to be equal to, and even better than, what are sold as the superior brands from the same works.

When great pressures and a small factor of safety are employed, or when the plates are exposed to very trying conditions, we cannot be too careful in the selection, and it is really a matter for congratulation that trustworthy plates are still to be obtained, and that makers are to be found who have been able to hold aloof from the reduction of prices, and at the same time reduction of quality, so general of late years. The most prominent among these are the so-called "Best Yorkshire" houses,* who only turn out one class of iron, and that the very best (if we except some of the Swedish and Russian brands). Their plates are as trustworthy in their character as can well be, and so highly are they esteemed that their employment is generally understood to absolve the boiler-maker from blame, in the event of failure from defect of material.

These plates are not more commonly used solely on account of their high price; and there is good reason to believe they will be able to hold their own in price until steel plates of an equally reliable and certain quality can be largely produced.

The use of the same brand by different makers, but for different qualities of plate, and the diversity in the names of the brands employed by numerous manufacturers throughout the country, are misleading and have been productive of much misunderstanding and annoyance. The "Crown" plates of one house may be of fair boiler-quality, whilst the same brand

* The best Yorkshire houses are :—The Low Moor Iron Works, near Bradford; Taylor, Brothers & Co., Leeds; Bowling Iron Co., near Bradford; Farnley Iron Co., near Leeds; S. T. Cooper & Co., Leeds; and The Monk Bridge Iron Co., Leeds. The other firms who make only "Best Yorkshire" *iron do not roll plates.*

of another house are only of ship quality, and not intended by the manufacturers for boiler-making at all, yet are unwittingly purchased by boiler-makers who have been in the habit of using "Crown" plates. The "Best Scrap" plates of one maker will be found to be of second quality, and only equal to the "Best Best" plates of another house, whose "Best Scrap" are equal to the "Best Best Best" of a third house. Some makers' "Best Best" plates are equal to the "Treble Best" of another house in the same district. As a rule, the price that any given brand commands in the market is the only criterion of its quality; and even this guide is not infallible, and is apt to mislead in a fluctuating market. It would be a great boon to boiler-makers and others who have to do with plates if some uniform system of branding them according to their quality could be agreed upon by those makers who roll three or four different qualities; and if each plate were stamped on both sides with its brand, date, and the maker's name. A few makers, in imitation of the "Best Yorkshire" houses, in branding their highest quality plates, do not denote the quality, but simply use a name or device, and rely upon the reputation of their plates for a sale.

The first quality to be sought for in a boiler plate is strength. This does not necessarily imply the mere power to resist being torn asunder by a dead weight, as in a testing machine, but the quality to withstand, without injury, the many and varying shocks and strains it is exposed to in the boiler yard and in actual work.

Many inferior plates exhibit as great a cohesive strength as those of better quality, their inferiority consisting in their brittleness or shortness, want of "body" or soundness, imperfect manufacture, and uncertain character or quality. Toughness and ductility combined with great tenacity, and also closeness and uniformity of texture and constancy of quality, are the properties and character to be sought for, and which are only to be found in the best brands.

The strength and quality of a plate are taxed in many ways. In the hands of the boiler maker and smith it may have to undergo the various processes of repeated heating and cooling, hammering hot and cold, bending, twisting, flanging, welding, and punching. Inferior qualities of plate cannot always be relied upon to bear the ordeal of repeated heating and cooling, as they often warp and twist, or waste away in a curious ·er, show defects of manufacture, and prove unworkable.

Some plates of otherwise fair quality will not bear hammering when red hot, a defect usually ascribed to the chemical properties of the iron. In the process of cold bending in the rolls, especially to a small radius, minute fractures sometimes occur on the outer surface of the plates of stubborn but fair quality. These are most frequently seen when the plates are bent across the grain, and doubts sometimes arise as to the depth the fractures penetrate into the body of the iron. Cracks in the scale adhering to the plates are sometimes erroneously taken for the fractures here referred to.

The manner in which a plate will bear flanging outwardly, whereby the fibres are either stretched or separated, as the plate is flanged across or along the grain, is generally considered the best test of its soundness and quality. It is certain that none of the inferior brands will stand this test with any degree of certainty. Those of somewhat better quality that bear flanging inwardly may, with care and skill, be made to stand outward flanging; but they cannot be depended upon. Plates of moderate quality may also be successfully welded if skilfully treated; yet, to ensure success, only very good or first-rate brands should be chosen where flanging, dishing, or welding is required. The effect of punching on plates of different qualities will be discussed in the chapter on riveted work.

The defect most commonly revealed in working boiler plates is lamination, from which plates even of the very best brands are not always free. This defect arises from the imperfect welding of the several layers which make up the thickness of the plate, and is usually caused by interposed sand or cinder which has not been expelled in the hammering and rolling during the process of manufacture. It is more frequent in thick than in thin plates, and is sometimes very difficult to detect in the new cold plate, although often discernible in the hot slab. It often happens that plates, which are passed as quite sound on careful external examination, are found to be severely laminated when subjected to heating and hammering, and prove totally unfit for working.

Blisters are of a similar nature, and arise from the same cause as lamination. Sometimes they appear as mere surface defects, and are of no consequence; but their appearance may be an indication of the want of care or skill in the making of the plate, and is sure to excite suspicion. At other times the blister runs from the surface far into the body of the plate, and its area may be *measured by* feet. It frequently happens that

these defects pass undetected through the closest scrutiny and test by hammering, but disclose themselves soon after the boiler is set to work, especially if the plate be exposed to sudden variations of temperature. When a blister does not run out to the surface or edge, it will possibly never be detected, unless it is subject to alternate heating and cooling, as in a furnace-plate, where the great heat on one side, compared with that on the other, will sooner or later take effect; and even here it may be years before it bursts open. In the plates over the fire-grate of an externally-fired boiler, such a blister may prove a very serious defect, calling for the immediate replacement of the plate, cutting out and patching in such a case being but a penny-wise proceeding.

After quitting the boiler-maker's hands, the test of every-day work will render manifest a wide difference in the behaviour of plates of various qualities. Inferior brands of brittle and badly refined iron will rapidly show unmistakable signs of weakness, if placed under the trying ordeal of bearing the alternate impingement of a fierce flame and currents of cold air. The rapid variations of temperature caused by the sudden and frequent openings of the furnace door and leakage of cold air at the fire bars and bridge will tell, sooner or later, on any kind of iron, but much more quickly on brittle than tough qualities.

On the delivery of a batch of boiler-plates from the maker's, the name and brand of quality on each plate should be ascertained, and care should be subsequently taken to keep the brand on the outside of the shell, or on the fire side of the furnace-tube, in a position where it can be afterwards readily discovered. Each plate should be gauged, or, still better, weighed, in order to ascertain the exact thickness, the comparison of which with the extent of departure from specification allowed to the maker will determine whether the plates are to be accepted or rejected. Each plate should then be examined on its sides and edges for surface defects, such as flaws, blisters, lamination, or marks and indentations caused by want of care in the rolling, the discovery of which may justify the rejection of the plate. In order to test its internal soundness, it should be marked off with a chalked line into squares of four or six inches, and conveniently suspended or supported on edge, to be tapped all over with a light hammer. Where solid the blows cause a sharp ringing sound; but a dull heavy sound indicates the presence of lamination or other defects. Both sides of the plate should be thus tested. Should any doubt arise as to the soundness by this

acoustic test, the plate should be prepared for fur.hor testing by supporting it horizontally on two edges, or still better, at its four corners, and strewing the upper surface with fine sand. The doubtful portions being then lightly tapped on the under side, the sand will be thrown off by the vibration, if the plate be sound; but if laminated the sand will remain stationary. Yet all ordinary methods of testing may fail to detect hidden internal defects, which may reveal themselves as soon as the plate is operated upon at the forge, or possibly not until the plate has been some time in use in the boiler. What is wanted is some magnetic or similar test, such as that proposed by Captain Saxeby, which, however, must be reliable and capable of easy application.

In cutting the plate from the slab some specifications require that a distance of from 2" to 4" shall be left from the nearest defect or cracks at the edge. The plates are also sometimes ordered sufficiently large to admit of a test-strip being cut off, in order to ascertain the quality and tenacity by breaking.

All plates of the very best quality having a longitudinal tenacity of 24 tons per square inch of section, and an ultimate elongation of about 12 per cent., and not exceeding one inch in thickness, should bend double along or across the fibre when red hot.

"Best Best" plates one inch thick and under, having a longitudinal tenacity of 21 tons, and an ultimate elongation of about 7 per cent., should admit of being bent hot, without fracture, lengthways to 130°, and crossways to 100°.

For the cold forge test plates of the very best quality, $\frac{7}{16}$ inch thick and under, should bend double without fracture.

Good boiler plates should bend cold, without fracture, to the following angles:—

Thickness.	Along.	Across.	Thickness.	Along.	Across.
1"	15°	7°	$\frac{7}{16}$"	55°	25°
$\frac{7}{8}$	20	10	$\frac{3}{8}$	70	35
$\frac{3}{4}$	30	15	$\frac{5}{16}$	80	45
$\frac{5}{8}$	40	20	$\frac{1}{4}$	90	55

The radius of the corner over which the plates are bent should not exceed half an inch. The angle to which the plates can be *bent without* fracture will depend greatly upon the

skill of the smith who heats and operates upon them. A plate that will bear the test with a number of sharp light blows, will often fail when a heavy hammer is used. By striking the plate along its surface it can be successfully bent to a much greater angle than when the blows are dealt perpendicularly to the surface. The plate will also stand the bending much better if it is performed uniformly along its whole width.

Rivets and bars for boiler work are seldom tested for their tensile strength, but their quality is usually ascertained by forge tests. A good rivet, cold, will bend double without fracture. The head of a good rivet should flatten out, by hammering when hot, to about $\frac{1}{8}$ inch thick, without fracture or fraying at the edge. A hot rivet-shank or bar of iron, when flattened down to a thickness equal to about one-half its diameter, should bear a punch driven through it without fracture at the hole.

There has been no lack of experiments to ascertain the tensile strength of wrought-iron plates of different qualities, and of ordinary thickness. Many of these are, however, not accompanied with sufficient information to make them of much value. The results of Mr. Kirkaldy's experiments on plates and bars are in many respects the most reliable and valuable yet recorded. These verify the commonly received opinion that good boiler plates may be considered as having an average tensile strength per square inch of section of 21 tons along the fibre, the strength being generally about ten per cent. less across the fibre. The strength of Best Yorkshire plates may be taken at 24 tons along the fibre, and 22 tons across.

The strength of round and square bars is superior to that of plates of equal quality, the superiority being most marked in iron of inferior brands. This circumstance is usually ascribed to the increased amount of rolling the bars undergo. Taking Mr. Kirkaldy's experiments as our guide, we find that ordinary bars, so far as their tensile strength is concerned, are more on an equality with "Best Yorkshire"-bars than was found to be the case with plates. The average strength of bars may be taken at 25 tons per square inch of section. It must not, however, be inferred from this that there is no superiority in "Best Yorkshire" and very best Staffordshire bars over those of ordinary make. The former are more reliable and uniform in quality, and exhibit a superior ductility when compared with those of inferior quality, and stand smithing very much better.

By way of explanation it may be here observed that when a *plate is broken so* that the line of fracture runs parallel with the

fibre, it may reasonably be said to be broken along or in the direction of the fibre; and when the fracture is perpendicular to this, across the fibre. This is, however, not the sense in which the terms along and across the fibre are usually employed. When we speak of a plate being broken in the direction of the fibre, we refer to the direction in which the strain is applied to produce fracture; and similarly when speaking of a breakage across the fibre. There is then evidently a discordance between our modes of expressing the directions of bursting fractures and tearing fractures relatively to the strains which produce them.

On breaking a plate or bar of wrought-iron, the fracture presents an appearance by which the quality of the iron may in some measure be determined. The fracture is designated on the one hand as fibrous, tough, fine, silky, close-grained, red-short, or on the other hand as crystalline, coarse, open-grained, brittle, cold short. Notwithstanding all that has been written concerning the quality and treatment of iron, and their influence on the appearance of the fracture, first pointed out, I believe, by Dr. Percy, and so ably shown by Mr. Kirkaldy, there still exists a great deal of misapprehension on the subject. A wide-spread notion prevails that all good wrought-iron should present a fibrous appearance; by this being meant, that when broken, no matter how, the fibres should appear drawn out. Now, the manner in which the breakage is effected is all important in influencing the appearance of the fracture. The best plates or bars rolled, as well as the worst admissible for boiler making, if broken short off or snapped in two, will display a short crystalline fracture, quite even and straight; but whether it be fine or coarse will depend entirely upon the quality of the iron. On the other hand, if the iron be gradually torn asunder, it will show fibre, the fracture being more or less rugged or irregular, and possibly at the same time mixed up with the fibres a small amount of crystalline fracture, the fineness or coarseness of the whole being an indication of the quality.

When broken suddenly the best qualities of plate and bar exhibit a fine close-grained uniformly crystalline fracture, even silky, of a light, silvery colour, the appearance in the harder descriptions approaching to that of steel. The appearance of indifferently refined and inferior qualities is coarser, usually of a darker colour, more or less uneven or open, exhibiting large facets, and approaching some descriptions of cast iron. When *broken gradually* good iron presents a well drawn out

close fibre, of light greyish hue, whilst inferior qualities give a shorter, more open, and darker fibre.

A bar or strip of plate can be broken suddenly by a sharp blow, when nicked with a chisel all round or on both sides, the nicks being made exactly opposite each other. By making a slight nick only on one side, and gradually bending the iron away from it, the strip will have time for the exercise of its ductility, and display abundant fibre.

It may be here remarked that metal is to be found enjoying the name of wrought iron which will test the ingenuity of any one to break it gradually so as to display fibre; it should be needless to add that such rubbish must never be used for boiler making.

"In the case of the fibrous fracture, the threads are drawn out and are viewed externally: in the case of the crystalline fracture, the threads in clusters are snapped across, and are viewed internally or sectionally" (Kirkaldy).

When old broken boiler-plates exhibit fibre at one side, and a crystalline appearance at the other, it is sometimes said that one side has deteriorated more than the other; but the fact probably is, that in the act of breaking one side has parted gradually, probably by the cross action of the strain, and as the section became diminished the other side has parted suddenly.

When good ductile iron is gradually torn asunder it draws out or stretches to a considerable extent, causing a diminution of sectional area at the fractured part, which should always be compared with the original sectional area of the specimen in judging of the quality. An inferior bar or plate may bear as great a tensile strain as a similar specimen of superior quality, say 23 tons per square inch of original area, but on comparing their fractured areas it will generally appear that the latter has been drawn out considerably, and actually sustained 30 tons or more per square inch of fractured area, whilst the inferior specimen, having stretched but little, has not sensibly diminished at the fracture. It is owing to this fact that good ductile iron is so much more trustworthy than badly refined or cold-short iron where sudden strains occur. The one will stretch where the other will snap.

It is often affirmed that wrought iron changes from fibrous to crystalline after enduring long-continued cold-hammering, vibration, tension, jarring, and other strains, or after long exposure to the influence of heat, or alternate expansion and *contraction when* used for the plates of a boiler-furnace. Even

the very best plates, after from ten to twenty years' use in a boiler, have frequently been found to break without stretching, at the same time displaying a crystalline fracture. It has been said that this indicates a change having taken place in the nature of the material, and that from being fibrous and tough it has, through some unexplained cause, become crystallised and brittle, or that it has lost its nature in consequence of the treatment it has undergone, whatever that may have been. Now there is no doubt that the strains and other causes mentioned have a tendency to make good iron become brittle and liable to snap suddenly under the same treatment that would originally have torn it gradually, and in so far a change is produced in its nature. This snapping, and not the fatigue of the metal, is, however, the direct cause of the crystalline fracture, which is but a necessary consequence of the suddenness of the breaking, and not a property of the iron itself. To say it snaps readily because it has become crystalline is to confound the cause with the effect. It is erroneous to say the fibrous nature has passed out of the iron, for its ductility can, to some extent at least, be restored in most cases by simply heating to a bright red, and slowly cooling the iron, or failing that, by hammering or rolling it while hot.

By heating to redness and suddenly cooling a piece of wrought iron, it will become liable to snap, producing the same effect as cold-hammering. The explanation of this is not obvious. It may in both cases be owing to the loosening of the crystals into which the composition of the material ultimately resolves itself. To this cause may also be attributed the same tendency to snap after long-continued jarring, or, alternate expansion and contraction.

The restoration of the toughness by the application of heat in such cases, and still more by the application of pressure, may be due to the consequent restoration of the crystals to their original positions.

It may be maintained that all boiler-plate worthy of the name is fibrous; whether its hardness makes it liable to snap, and therefore appear crystalline, depends on its original character and the treatment it has undergone. No fine iron can, however, by any treatment, except burning, be made to appear coarse, and the fibres of the poorer descriptions cannot, without re-working, be made to appear fine and close grained.

It is from a want of knowledge of the above facts that false opinions are *so often* expressed respecting the qualities of

plates. The following instance is perhaps not too well known to bear repetition. A scientific witness at an inquiry into the cause of a boiler explosion, after expressing himself competent to distinguish between bad and good iron, was handed three broken specimens to examine and pass an opinion upon. These he severally pronounced as good, bad, and indifferent. They were all cut from the same strip of plate, and artfully broken to present different looking fractures, by which the witness was deceived.

It is not unusual to find eminent engineers at inquests and inquiries delivering judgement on the quality of iron without anything to base their opinion on except the load per square inch required to tear the material asunder.

As it has just been attempted to show, this can give no true indication of the quality of a plate. The precise character of the fracture, contraction at broken area compared with original section, together with the shape and temperature of the test-piece, direction of strain, and manner in which the breaking-load is applied, as well as the amount of the load, must all be considered.

If the plate whose quality is in question has been taken from an old boiler the age should be known and the position in the boiler, along with any other circumstances tending to throw light on the nature and amount of the strains to which it has been exposed, and which may influence the manner of breaking.

As shown by Mr. Kirkaldy, good ductile iron can be made to appear crystalline when pulled asunder in the testing-machine simply by confining the minimum sectional area where fracture will occur to one point, or to a very short length, as by turning a narrow groove in a round bar. By so reducing the section the shape is rendered unfavourable for drawing out, and the specimen is more liable to snap than when the minimum sectional area is uniform for at least five or six inches.

In all cases where the elongation and reduction of the fractured area are lessened by cold rolling, hammering, altering the shape of test-piece, or by applying the strain suddenly, the breaking load of the material will be increased in proportion to the increased area of fracture.

For much of our knowledge of the variation of strength in boiler plates and bars at different temperatures we are indebted *to the experiments* of Sir W. Fairbairn. The annexed

tables give the results of these, from which it may be seen that from 0° to 400° Fahr. the tenacity of plates is practically uniform. The difference between the strength of wrought iron and copper at ordinary working temperatures is very striking.

PLATES.			RIVET IRON.	
Temperature Fahr.	Drawn asunder in the direction of the fibre.	Drawn asunder across the fibre.	Temperature Fahr.	
	Breaking weight per sq. in. in tons.	Breaking weight per sq. in. in tons.		Breaking weight per sq. in. in tons
0°	21·879	——	30°	28·26
60	22·414	18·689	60	28·05
114	18·462	19·714	114	31·61
212	19·963	20·392	212	35·39
270	19·651	——	250—270	36·89
340	22·307	18·789	310—325	37·52
395	20·574	——	415—435	37·47
dull red	——	15·299	red heat	15·62

The Staffordshire plates employed in these tests do not appear to have been of good quality. The maximum strength of rivet iron—39 tons—appeared to be attained at a temperature of 320°. This is above the temperature at which the mean strength of the plates—$20\frac{1}{2}$ tons—was attained ; little or no change is observable in the strength of the plates, whilst that of the bars is increased nearly one-half.

STEEL.

Steel is popularly described as iron holding a mid-position between cast and wrought iron with respect to the amount of carbon it contains, cast iron having from 6 to 2 per cent. of carbon, steel from 2 to $\frac{1}{3}$ per cent., whilst wrought iron has a percentage varying from $\frac{1}{3}$ to $\frac{1}{4}$.

It is beside the purpose of this work to inquire closely into the accuracy of the above description, but it is beyond question that the elimination from ordinary cast iron of other ingredients besides the surplus amount of carbon is essential for the production of good steel.

To the intimate chemical union of this medium amount of carbon are usually ascribed the remarkable characteristics by which the higher *classes of steel* are distinguished. Whatever

influence the presence of other ingredients may have upon its quality, it has been satisfactorily shown that the tensile strength of steel is intimately connected with its degree of hardness, and both these properties are proportioned to the amount of carbon in chemical combination. Up to a certain point, which varies with the quality of the material, the tenacity of steel may be said to increase with its proportion of carbon. With Bessemer steel the greatest strength, about 70 tons per square inch, is reached when the carbon contained is about $1\frac{1}{4}$ per cent., the elongation being then about $2\frac{1}{4}$ per cent. Beyond this degree of carbonisation the steel becomes gradually weaker. When the contained carbon is about $\frac{1}{3}$ per cent., the breaking weight is only about 30 tons per square inch, with an elongation of 16 per cent. With less than $\frac{3}{8}$ per cent. Bessemer steel will not temper, with more than $\frac{5}{8}$ per cent. it will not weld, and the presence of more than 2 per cent. is said to render it useless for forging. These amounts, however, vary with the quality of the material, which is influenced by various causes.

Besides the chemical distinction just mentioned, it is difficult to name, without risk of contradiction, a single property common to all the various classes of metal that come under the denomination steel, by which they may be distinguished from wrought iron unless it be superior tensile and compressive strength combined with greater resilience and a higher limit of elasticity, and even in these respects the difference in some exceptional cases is not very marked.

The higher classes of steel, which will harden and temper, and even weld in some cases, not being adapted for constructive purposes do not call for special comment, and we shall restrict ourselves to the discussion of the properties belonging to the milder qualities, which alone are fit for boiler making.

It was probably the high degree of tenacity and ductility exhibited by tool and spring steel that first drew attention to the advantages offered by this material for constructive purposes. Its high price, however, long stood in the way of its being largely adopted, and this obstacle was only removed by the introduction of new methods of manufacture, which can as yet be termed improvements only with respect to their commercial success, and not as affecting the quality of the material.

According to the mode of manufacture, the material is designated crucible cast steel, Bessemer steel, and puddled steel. Homogeneous metal is a kind of mild cast steel. The bars and plates of this and the two first mentioned descriptions are

made from a single ingot; but in puddled steel they are composed of many small pieces piled and welded together like puddled-iron, and are consequently liable to the same defects.

In comparing the properties of steel and iron plates there can be no dispute that the nature of the processes employed in the production of cast-steel is immensely superior to that employed in the manufacture of wrought iron for ensuring a uniform texture in the material. Cast-steel plates made from a fluid mass run into a single ingot, and well worked under the hammer, are likely to be perfectly homogeneous and free from the imperfect welds and internal defects caused by the presence of cinder and slag, found even in the best puddled-iron, which being built up of numerous small pieces, all more or less properly welded together, is entirely dependent upon the skill and care exercised in its production, for its homogeneity and freedom from lamination, blisters and other defects, internal and superficial. It must, however, be admitted that the homogeneity of a bar or plate of cast steel is frequently far less perfect than we might expect, and with the best mild steel, although we may generally rely upon uniformity of character in any single plate, the same uniformity of quality and character running through a considerable number of plates cannot be generally obtained.

Notwithstanding its superiority in tensile strength and other properties, steel is as yet in comparatively small request for boiler-making. The feeling that still prevails against its employment cannot be attributed to the existence of any inherent defect in the nature of the material, revealed by the trying ordeal of actual work in a boiler, as is known to be the case with cast iron. No doubt many absurd objections are still heard against the employment of steel plates, such, for instance, as that it expands and contracts to such a degree on the application and withdrawal of heat as to render it unfit for boiler furnaces; that on heating it warps and twists so much that it cannot be used where the plates require to be worked hot, or that it is liable to fracture at any moment without warning and without any known cause.

That there is still a certain amount of treachery in steel plates when subject to blows and sudden strains cannot be denied, but when closely inquired into the prejudice against it appears to have grown out of the distrust caused by the occasional failure of the hard steel plates employed at the time of the introduction of this material for boiler-making and ship-building, when its properties were not so well understood as at

present. The desire to take advantage of their high tensile strength led to the employment of plates of so hard a quality as we now know could not be otherwise than brittle and untrustworthy. It has been found by experience with different qualities that in steel plates toughness is incompatible with great tensile strength, and these two qualities may be considered as being in the inverse ratio to each other. If we insist upon having a tensile strength of 40 tons and upwards, we must be prepared to find a steel hard and brittle, and therefore not adapted for boiler-making. In order to ensure freedom from brittleness, from 33 to 36 tons per square inch appears to be the maximum tensile strength that can be allowed. Steel plates of this strength can be made sufficiently tough and ductile to render them safe and also tolerably easily worked. This latter is a most important condition, on which depends in no small degree the commercial success of the material for boiler-making.

There can be little doubt that the use of steel for boiler plates has been retarded by the want of knowledge of its properties and the consequent difficulty sometimes met with in working it. The result of this is a disposition on the part of the great majority of boiler-makers to avoid using it as much as possible.

Good steel plates, even of the mildest quality, are affected by fire in quite a different manner from iron plates. This exercises an important influence on their behaviour when submitted to the operation of flanging and bending at a high temperature. In flanging wrought iron it is necessary to heat only a short length of the plate at a time, but with steel it is advisable to heat a much larger portion of the plate than can be worked by the ordinary slow process of flanging at each heating, in order to prevent injury. Indeed, it is much better to complete the flanging at one or at most two heatings, operating gradually to the same degree on the whole extent of the part to be flanged. This can, of course, in the majority of cases be done only by special machinery, which is now being more extensively introduced into boiler-works for the purpose. After such an operation is completed, the steel plate cannot be trusted to stand rough usage at the part that has been highly heated. It is, therefore, advisable to anneal it in order to restore its toughness. The process of annealing consists in slowly heating the plate to a dull red heat, and allowing it to cool again slowly *and uniformly*. Immersion in fine ashes or sand is sometimes

adopted for this purpose, but care must be taken that the plate be not so highly heated when the immersion takes place, as to induce a chemical change in its properties when in contact with the non-conducting substance. The appearance of the plate is sometimes impaired by annealing, and when required to be extensively applied the process of annealing becomes an expensive one.

In working a steel plate cold, care should be taken that there are no flaws or cracks, as, except in the very mildest qualities, they are liable to cause fracture. When bent cold, or subject to severe straining or jarring, even a ragged edge has a tendency to make the plate snap or break suddenly. This phenomenon is also common to the harder and more brittle descriptions of wrought iron, but in a less degree. For this reason, in working cold or bending cast steel plates, especially if at all hard or unannealed, all sharp edges and rags left by punching, shearing, or chipping should be carefully removed.

As an instance of the special treatment required by steel, it may be mentioned that in hammering down a screwed stay-bolt-end of steel, with the thread left on, there is a risk of producing foliation, which renders the head liable to snap off. To guard against this, it is advisable to turn the thread off the end of the stay-bolt, which enables it to be riveted over successfully.

Respecting the effect of punching on steel plates, we have no lack of experiments to show how plates of different qualities are affected by this process. It may be here remarked that it is mostly to the researches of shipbuilders that boiler-makers are indebted for exact experimental knowledge of the properties of steel plates. One of the principal results obtained, both from experiments and experience of the material in actual riveted work, is that steel plates of average suitable quality are more injured than wrought-iron plates by punching. Roughly speaking, the injury is in proportion to their hardness. For this reason most makers of steel boilers have abandoned punching in favour of drilling, and with satisfactory results.

The increased expense of drilling plates for shipbuilding led to attempts to discover some means of obviating the injurious effects of the punch, and annealing was found to restore the toughness of the punched cast-steel plate, if not entirely at least to some extent.

Some tests were conducted by Mr. Sharp, of Bolton, on the comparative strength of drilled and punched holes, when the result was *found to be for* an average of three trials 49 per cent.

in favour of drilling. The plates were Bessemer steel $\frac{5}{16}''$ thick, three being drilled, and three punched with $\frac{5}{8}''$ holes at $1\frac{1}{2}''$ centres. The average breaking strengths were respectively 36·25 tons and 24·33 tons per square inch.

In some experiments on the strength of punched steel plates, conducted by Mr. Barnaby, at Chatham, the average ultimate strength of 8 unannealed $\frac{1}{2}''$ plates was found to be but 21 tons per square inch, whereas 8 similar plates, after annealing, had an average strength of $32\frac{3}{4}$ tons, being an increase of about 55 per cent. or $11\frac{3}{4}$ tons per square inch. To ensure uniformity of quality in the test pieces, eight $\frac{1}{2}''$ plates were punched with four $\frac{5}{8}''$ holes, and then cut in two, making two strips from each plate for testing, only one of which was annealed.

The annealed strips showed a much greater uniformity of resistance than the others, the ranges of strength being respectively $5\frac{1}{2}$ tons and $9\frac{1}{3}$ tons. The former also bore the usual tests of cold bending much better than the latter.

The clearance of the die has also been found to influence the strength of the plate after punching.

Mr. Sharp found, as the result of four experiments with $\frac{11}{16}''$ holes punched in a $\frac{1}{2}''$ unannealed plate, that when the clearance was $\frac{3}{16}''$, tantamount to a considerable countersink, the plate was 25 per cent. stronger than when the die was only $\frac{1}{16}''$ larger than the punch.

Some further experiments recorded by Mr. E. J. Reid, for ascertaining to what extent this effect could be relied upon, were made with $\frac{1}{2}''$ Bessemer steel plates punched with $\frac{5}{8}''$ holes. Four of the test pieces had $\frac{1}{16}''$ and four had $\frac{3}{16}''$ taper in the holes. The gain of strength was about 10 per cent. in favour of the increased taper. Mr. Reid remarks that much of the injury done to Bessemer steel is due to the strain at the under side of the hole. Indications of this in minute cracks may be detected on close examination. A little increase in clearance removes these, and gives the good result above indicated.

The same authority gives an account of some experiments with $\frac{1}{4}''$ puddled steel plates, 2·7 inches broad, having an average tensile strength of $31\frac{1}{2}$ tons per square inch lengthwise, and $27\frac{1}{2}$ tons across the fibre. The average strength both ways was about four tons per square inch of nett section less for punched than for drilled holes, which were $\frac{5}{8}''$ diameter—equivalent to a removal of nearly $\frac{1}{4}$ the section of the strips tested.

Further experiments with strips $4\frac{1}{4}''$ wide, having two $\frac{9}{16}''$

holes equal to a removal of rather more than one quarter the section, showed a loss of 6 tons per square inch of nett section.

Some experiments were made with eight strips of $\frac{1}{4}''$ puddled steel, 4·06 wide, with two $\frac{1}{2}''$ holes punched at equal distances from each other and the edges of the strip. Four of these pieces were annealed after punching, and four were not. The results showed there was no gain from annealing, exhibiting a marked difference from the Bessemer steel in this respect. The tensile strength was 34 and $30\frac{3}{4}$ tons per square inch along and across the fibre.

Eight tests with $\frac{3}{8}''$ crucible cast-steel plates gave an average tensile strength of 26·63 tons lengthwise, and 26·21 tons per square inch across the fibre. Similar plates $\frac{5}{16}''$ thick exhibited a gain in strength from annealing after being punched. The loss of tenacity by punching was, lengthwise and crosswise respectively, 7 and $3\frac{3}{4}$ per cent. The gain of annealed over unannealed was 14 per cent. lengthwise and 12 per cent. crosswise.

From the above results it will be seen that Bessemer steel in punching sustains a very material amount of injury, and should therefore be either drilled or else annealed after the operation, when punched. The puddled steel plates experimented upon did not suffer so much from punching, nor was their strength so fully restored by annealing.

In consequence of their lower price, steel boiler plates are mostly made of Bessemer steel of the mildest quality, but crucible cast steel is also sometimes used. Their tensile strength cannot be taken at more than 33 tons and 36 tons respectively, or about 57 per cent. and 71 per cent. greater than wrought iron, the elongation being from 16 to 25 per cent. when the quality is good. A steel boiler-shell may therefore be made of plates at least one-third less in thickness than a similar shell of wrought iron, to ensure equal strength. But the reduction in thickness of the internal flues, which are subject to a collapsing pressure, cannot be taken in the same proportion. In compressive strength and stiffness mild steel is indeed superior to wrought iron (the ratio being about the same as for the tenacity) ; but in estimating the collapsing pressure of a furnace-tube of ordinary dimensions we shall find that, for a given pressure, the thickness cannot be reduced more than about one-sixth, if we substitute steel for iron, which gives us $\frac{5}{16}''$ instead of $\frac{3}{8}''$ plates.

In *favour of the steel*, however, it may be remarked that

the wasting caused by the action of the heat in the furnace is less in thin than in thick plates. For this reason, and also on account of the hardness of the steel resisting abrasion better, steel plates are more durable than iron.

Besides the weight saved by using steel,—often a most important consideration,—it may be urged that the thinner plates will conduct the heat more rapidly, and give a corresponding superior evaporative efficiency. This superiority is not, strictly speaking, in proportion to the reduction of thickness, the relative conducting powers of steel and iron being about 218 and 244. In the case of an internal flue-tube the gain and loss would be about equal. But, as we shall see in the chapter on Heating Surfaces, we cannot reckon upon any gain in evaporative efficiency by using a slightly thinner and better conducting material.

The effects of corrosion on steel boiler plates will be considered in its place, along with the wear and tear of boilers. It may, however, be here observed that, if the corrosion acts equally on both materials, the strength of a thin plate will suffer more proportionately than a thicker one.

Experiments on the strength of steel riveted joints conducted and recorded by Mr. Kirkaldy seem to prove that for the size of rivet a greater diameter than double the thickness of the plate is required for riveting in steel with plates of the thickness and great tensile strength of those used in the experiments. The plates tested were all $\frac{3}{16}''$ thick by $3'$ broad, having a tensile strength of $43\frac{1}{4}$ tons. Some were in their usual soft state, and others were hardened in oil. In the former two $\frac{7}{16}''$ rivets failed by shearing, and with two $\frac{9}{16}''$ rivets the plate was torn across in two instances with a loss of 45·6 and 43·5 per cent. of tenacity compared with the solid plate. This shows a loss of strength in the nett section equal to about 7·2 per cent. In the hardened plates $\frac{7}{16}''$ and $\frac{9}{16}''$ rivets were sheared through. With a load only 15·9 per cent. less than that borne by the entire soft plate, the hardened plate cut through one $\frac{11}{16}''$ rivet, whilst the other remained good, the plate corner tearing off. These experiments, taken together with Fairbairn's on iron plates, show that in a single-riveted joint, with the rivets just large enough to fail before the plates, the loss of strength bears about the same proportion to the strength of the solid plate whether the joint be of iron or steel; also that hot rivets do not reduce the strength of the plate, and that the plates hardened in oil and joined together with rivets are fully equal in

strength to unjointed soft plates having the same gross sectional area.

The hardening in oil was found not only to harden, but also to considerably toughen the steel. Hardening in water reduced the strength. In these experiments the breaking weight of the rivet steel bar was about 38½ tons per square inch, and the mean shearing strength of the rivets in the joint was about 28½ tons, or 26·2 per cent. less than the tensile strength. Respecting the results of these experiments, it may be observed that the plates were of harder steel than can be trusted for boiler-making, and the gain in strength by hardening in oil was probably greater than would be found in using milder steel which does not temper. The plates also appear to have been considerably stronger than the rivets, which may in some measure account for the disproportionately large area it was found necessary to allow them.

Experience has shown that much greater care is required in heating steel rivets not to injure them, than is necessary when iron rivets are used, and they should be hammered down quickly before they have time to cool, and closing up by machine is preferable to hand riveting when steel rivets are used.

The use of any but the mildest steel should be avoided, as rivets of high steel sometimes become so hard after closing up that it is impossible to remove them when repairs are required. This is probably owing to the effect of some chill they receive in cooling, as might be caused by the water dropping on them, which is sometimes used for keeping the cup cool in machine riveting. The heads are readily enough knocked off, but the shanks will sometimes resist the hardest drill, necessitating the cutting out of the plates. The heads of steel rivets, if not carefully worked, are more liable to fall off than those of iron, by jars, careless caulking, or rough usage.

It is owing to the above difficulties that the use of steel rivets has been altogether given up by some boiler-makers, who prefer using iron rivets with steel plates. The usual pitch and diameter of rivets is in these cases generally adhered to. It is, however, advisable to reduce the pitch slightly, and to use a larger number of smaller rivets, to ensure tightness. In wrought-iron double-riveted lap joints and double-fished butt joints, with either single or double riveting, the strength of the rivets is usually in excess of that of the plates up to ½″ in thickness. By using the same size and pitch of rivets with steel plates the equality *in strength is more* nearly attained.

Mr. Kirkaldy records two experiments on the strength of welded steel bars. The results were very unsatisfactory, one bar breaking with a loss of 45 and the other of 59·6 per cent. Two other bars parted at the weld during the operation of forming the heads for testing. As the tensile strength of the unwelded steel bar was about $50\frac{1}{4}$ tons, it would not be so favourable for welding soundly as one of milder steel. It is considered that Bessemer steel having a tenacity of from 35 to 45 tons both tempers and welds badly. With a less strength it will not temper, but can be welded ; and with a greater tenacity it will not weld, but tempers well.

The following tests are those given by Cammell and Co. for steel plates :—

Forge test (*hot*).—All plates one inch thick and under to bend hot without fracture to an angle of 180°, both lengthwise and across the grain.

Forge test (*cold*).—All plates will admit of bending cold without fracture as follows :—

Bessemer plates :—tensile strength lengthwise 33 *tons per square inch.*

Thickness.	With the grain.	Across the grain.	Thickness.	With the grain.	Across the grain.
1	45°	25°	$\frac{7}{16}$	90°	70°
$\frac{7}{8}$	50	30	$\frac{3}{8}$	110	80
$\frac{3}{4}$	60	40	$\frac{5}{16}$	120	90
$\frac{5}{8}$	70	50	$\frac{1}{4}$	120	100
$\frac{1}{2}$	80	60	and under		

Crucible cast-steel plates :—tensile strength lengthwise 38 *tons per square inch.*

Thickness.	With the grain.	Across the grain.	Thickness.	With the grain.	Across the grain.
1	50°	30°	$\frac{7}{16}$	130°	100°
$\frac{7}{8}$	60	35	$\frac{3}{8}$	150	110
$\frac{3}{4}$	75	50	$\frac{5}{16}$	180	120
$\frac{5}{8}$	90	70	$\frac{1}{4}$	180	120
$\frac{1}{2}$	110	90			

CHAPTER IV.

RIVETING.

UNTIL boiler-shells and tubes of large diameter can be rolled from a solid block like tyres, or drawn solid like small tubes, the edges of both iron and steel boiler plates require to be joined either by welding or riveting.

But few if any engineers are now to be met with who would venture to maintain that the riveted lap-joints of a new boiler are stronger than the entire plate; yet this was the current opinion some forty years ago, however incredible it may now appear. It was only after numerous direct experiments had proved its fallacy that the error was abandoned. By what show of reasoning this view was arrived at, it is difficult to conceive. Perhaps the union of the plates was regarded as perfect; and then the conclusion would naturally follow, that the double thickness was stronger than the single. The nip of the rivet in cooling may have been accredited with a greater value than we are now inclined to assign to it.

Generally speaking, the riveted joints are the weakest portion of a new boiler, when there are no large unstrengthened dome or man-holes. Since the strength of a structure must be measured by its weakest part,—the strength of a chain by its weakest link,—the subject of riveting becomes all important.

Riveted joints are of various descriptions: those we are concerned with are designated single and double riveted lap-joints, single and double riveted butt-joints. The latter are made with either a single or double covering-strip, welt, or fish-plate, as the piece joining the plates is variously called. Double-riveted joints, both lap and butt, may have their rivets arranged one row directly behind the other, called chain riveting, or in zigzag fashion, which is most common and the best for boiler-making.

The rivets themselves are of various descriptions, or rather their heads are made in various forms. There is first, the ordinary conical or pointed head, which is formed by knocking down the point with light hammers. This shape is always employed where *the space* available for hammering down the

point is limited, as when effecting repairs with the boiler on its seat. Although to some extent employed in new work, it is not so well liked as formerly, there being nothing to recommend it but the facility of making and the shapely appearance it presents when well formed. The thinness of the collar renders it more vulnerable than the snap head when attacked by corrosion. The height of the conical head varies in different works, but it should be made about equal to $\frac{3}{4}$ the diameter of rivet. It is, however, commonly made too flat, which, besides having the defect of offering little material to withstand corrosion, frequently causes the head to be very brittle and easily detached by a single blow from a hand hammer. This brittleness is probably caused by the sudden cooling of the small quantity of iron for the point when inserted in the hole and flattened out, together with the amount of cold hammering the iron receives in finishing.

The snap or cup head is the best, and is formed by roughly hammering down the point; the form of the head being completed by holding a cup-shaped die on it, which is struck with a heavy hammer. The height of the snaphead should be about $\frac{5}{8}$ the diameter of rivet, but it varies considerably, being from $\frac{1}{3}$ to $\frac{3}{4}$ the diameter. The diameter of the head also varies considerably; the usual custom is to make the shoulder from $\frac{3}{16}''$ to $\frac{5}{16}''$ for rivets from $\frac{5}{8}''$ to $\frac{7}{8}''$ diameter.

Most makers avoid making the bottom of the head cylindrical or parallel, but bring it to a sharp edge to facilitate caulking. This shape is the best for machine riveting, where the edge of the head cannot be finished off as in cupping by hand, but usually requires to be subsequently dressed and caulked.

The countersunk head is formed by hammering down the point into the conical hole prepared for it; it is then usually dressed off with a chisel and hammer. Although extensively used in ship-building, its employment in boiler-making is almost limited to cases where even surfaces are required for mountings, &c.

Countersinking should always be avoided in riveting angle-irons, saddle-plates, or brackets, employed for securing stays, or wherever the force acts in the direction of the length of the rivet. Not only is the countersinking liable to leak under such circumstances, but the head has a very insecure hold of the plate, and is liable to be drawn through the hole by a much less pressure than is required to tear the rivet asunder.

The allowance made in the length of the rivet for forming

the head should be about $1\frac{1}{4}$ times the diameter for snap and conical heads, and about equal to the diameter for countersunk heads. In machine riveting the length requires to be $\frac{1}{8}''$ to $\frac{1}{4}''$ more than the above.

The tails of the rivets are generally made pan or flat shaped, except in machine riveting, where the cup or similar form is almost invariably employed.

In making the different-shaped heads the rivets may be closed up either hot or cold : the latter method is said to be employed to some extent in the United States, but very rarely in this country. The closing up may be effected either by hand or by machine worked by steam, water, or compressed-air power.

Machine riveting upsets the rivet and closes up the hole better than hand riveting, as the dead heavy pressure is exerted through the whole mass of the rivet, and the effect is not concentrated upon the point as it must be with a succession of light sharp blows from a hammer. The evil of the rivet not filling the hole well is sometimes aggravated in hand work by the blows being dealt on the circumference of the point, in order to form a shoulder speedily to resist the hammering, instead of letting them fall dead on the point, which should tend to make the rivet first fill the hole before the shoulder is formed.

The possible disadvantage of machine riveting is that the plates may not be nipped tightly together, and the rivet may be squeezed out between them, causing a permanent separation of the surfaces which should be in contact. The pressure of the machine not coming on to the plates until the hole has been filled, is sometimes not so effective in closing the joint as the lighter pressure brought upon the plates in hand riveting, where the men drop a few blows round the hole before operating on the rivet in order to set the plates close together.

Hydraulic riveting is more gradual, and is generally preferable to steam riveting, the pressure from which often comes upon the rivet with a violent blow, and does not allow time for the rivet to fill the hole so well as with the former method ; but it is still preferable to hand riveting, although the appearance of the last is the most pleasing to the eye.

As the result of numerous experiments by different authorities, the average tensile strength of good rivet iron may be taken at 24 or 25 tons per square inch. It is but seldom, however, that the tensile strength of a rivet is taxed in a boiler except in the flat end plate, mounting and stay attachments, where the stress tends *to tear off the heads*. In a lap joint and single-

fished butt joint the force pulling the plates asunder tends to shear the rivets through in one place only, in the direction of its diameter,—this is called a single shear. In a double-fished butt joint the rivet is exposed to a double shear, as the plates in parting asunder tend to cut the rivet through in two places.

It has been determined by experiment that the ultimate resistance to shearing is proportional to the area of the rivet, and is practically the same as the ultimate resistance to a direct longitudinal tensile stress, or 25 tons per square inch. As a rivet in double shear offers twice the area to resist breaking that it does in single shear, it should evidently be twice as strong in the former case as in the latter. The above cannot, however, be regarded as the shearing resistance of a rivet in actual boiler work, where its strength is affected by the heating and hammering down to fill the hole and to form the head, and in the second place by the tension produced by contraction in cooling.

In some experiments undertaken for the Admiralty at Chatham $\frac{3}{4}''$ rivets of best Yorkshire iron were found to have a mean single-shearing strength of 10 tons each (a fact easily remembered, and of some use, as $\frac{3}{4}''$ is a very common size for boiler rivets), and a double-shearing strength of 18 tons. These strengths correspond respectively to about $22\frac{1}{2}$ tons and $20\frac{1}{4}$ tons per square inch of sectional area sheared through. Mr. Doyne found the strength of rivets of various sizes and descriptions in ordinary riveted work averaged 18·82 tons for single shear and 17 tons for double shear per square inch of sectional area. The longitudinal tensile strength of the rivet not being given, we are unable to estimate the loss of strength due to riveting up.

The shearing strength of iron rivets with thin steel plates has been found to be less than with iron plates of the same strength. This is probably due to the harder steel cutting into the iron of the rivet. The average of eight experiments by Mr. Sharp with steel plates and iron rivets gave 18·68 tons per square inch.

We may safely take the strength of the rivet as equal to the tensile strength of the plate, or 21 tons per square inch for either single or double shear.

It is obvious that the contraction of the rivet in cooling must press the plates between the heads closely together. The tension thus caused, although affecting the shearing strength of the rivet, must add materially to the strength and tightness of *the joint.* Mr. E. Clark, in his work on the Britannia and

Conway Tubular Bridges, gives an account of some interesting experiments to ascertain the amount of friction caused by the contraction of rivets in cooling, accompanied by some excellent remarks :—

"The contraction of a wrought-iron rod in cooling is about equivalent to $\frac{1}{10000}$ of its length from a decrease of temperature of 15° Fahrenheit, and the strain thus induced is about 1 ton for every square inch of sectional area in the bar. Thus, if a rivet 1 inch in section were closed at a temperature of 900°, it would, in cooling, decrease in length $\frac{60}{10000}$ of its length, and, if its elasticity and strength remained perfect, would produce a tension of 60 tons. The ultimate strength of rivet iron, however, being only 24 tons, the rivet would, in cooling, be permanently elongated, and would continue when cool to exert a tension of 24 tons, provided its elasticity remain uninjured by the strain. Thus, if the rivet were not in contact with the plates, excepting at the head and tail, the plates would be held together by a pressure of 24 tons, and this friction would have to be overcome before the rivet came into action as a mere pin.

"The following experiments were made to ascertain the value of friction induced by this cooling and consequent contraction of the rivets, and the force requisite to slide the plates over each other. For this purpose three $\frac{5}{8}$-inch plates were riveted together with a single $\frac{7}{8}$-inch rivet, but the hole in the centre-plate was oval, and very much larger than the rivet, being $2\frac{1}{2}$ inches in its longest diameter. Weights were suspended from the centre-plate until it slipped and bore upon the rivet; it supported 5·59 tons before it began to slide, which it did abruptly.

"The experiment was repeated with the addition of an $\frac{1}{2}$-inch plate of iron riveted on each side, between the heads of the rivet and the plates, making the shank of the rivet $2\frac{7}{8}$ inches long; 4·47 tons caused the plates to slide.

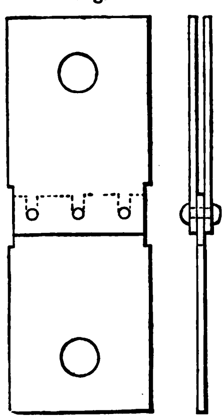
"The last rivet having been found faulty, the experiment was repeated exactly as before, and the plates sustained 7·94 tons before they slipped.

"In the next experiment a $\frac{7}{8}$-inch rivet was inserted through two $\frac{5}{16}''$ plates, with large holes, with a $\frac{5}{16}$-inch washer on each side next the rivet-head. This combination supported 4·73 tons before it gave way."

In his work on "Ship-building," Mr. E. J. Reed records some experiments of a more detailed description than those of Mr. Clark.

"Three plates were united by what is known as a 'chain-joint'—that is, the ends of the two outer plates overlapped the end of the middle plate. The connection of the plates was made by three rivets passing through the lap, the rivet-holes in the outer plates being filled by the rivets, but the bearing surface of the holes in the middle plate being slotted out, as shown in the sketch (fig. 2). It will thus be obvious that

Fig. 2.



when a tensile strain was brought upon the middle plate, the amount of the friction could be measured by the force just able to produce a sliding motion. The breadth of the lap was three diameters, the rivets were a diameter clear of the edge of the plates, and their pitch was four diameters. There were two sets of experiments made with iron plates and rivets, and in each set two experiments were made with rivets having heads and points snap headed; two others with rivets having pan heads and conical points; and the remaining two with rivets having countersunk heads and points. The experiments were made in duplicate, in order to reduce the chance of error. The first set of experiments were made with $\frac{1}{2}$-inch plates, $8\frac{1}{4}$ inches wide, the rivets being $\frac{3}{4}$ inch. The results were as follows:—

Description of Rivet.	Friction per Rivet.		
	1st Experiment.	2nd Experiment.	Mean.
	Tons.	Tons.	Tons.
Snap heads and points . . .	5·14	4·21	4·67
Pan heads and conical points .	5·26	4·81	5·0
Countersunk heads and points.	4·56	3·74	4·15
Mean of the three . .	...	...	4·61

The second set of experiments were made with plates 11 inches wide and $\frac{7}{8}$-inch thick, the rivets used being 1 inch diameter. *The following* results were obtained under the above-stated *conditions of pitch* of rivets, lap, &c. :—

Description of Rivet.	Friction per Rivet.		
	1st Experiment.	2nd Experiment.	Mean.
	Tons.	Tons.	Tons.
Snap heads and points . . .	5·84	5·64	5·7
Pan heads and conical points .	6·87	7·24	7·0
Countersunk heads and points .	4·56	4·09	4·3
Mean of the three . .	...	...	5·6

"In addition to these experiments with iron plates and rivets, two other sets of experiments were made with steel plates and rivets of exactly the same dimensions as those used in the former experiments, the pitch of rivets, breadth of lap, &c., being in each case identical with those previously given. With $\frac{1}{2}$-inch plates and $\frac{3}{4}$-inch rivets, the results obtained were as follows :—

Description of Rivet.	Friction per Rivet.		
	1st Experiment.	2nd Experiment.	Mean.
	Tons.	Tons.	Tons.
Snap heads and points . . .	3·86	4·09	3·98
Pan heads and conical points .	4·79	4·79	4·79
Countersunk heads and points .	3·63	3·43	3·53
Mean of the three . .	...	...	4·1

With $\frac{7}{8}$-inch plates and 1-inch rivets, the following results were obtained :—

Description of Rivet.	Friction per Rivet.		
	1st Experiment.	2nd Experiment.	Mean.
	Tons.	Tons.	Tons.
Snap heads and points . . .	6·43	5·49	5.96
Pan heads and conical points .	5·49	None made.	5·49
Countersunk heads and points .	5·14	4·91	5·02
Mean of the three . .	...	...	5·49

"It *thus appears that* rivets with pan heads and conical

points have the advantage over both the other descriptions of riveting. The only exception to this is found in the second set of the experiments with steel plates and rivets ; but, as only one experiment was made, the result cannot be relied on. It also becomes evident that countersunk riveting causes much less friction than the other systems. On comparison, it will be seen that in nearly all cases steel plates and rivets give less friction than iron, the only exception being the cases of rivets with snap heads and points, and those with countersunk heads and points, in the same set of experiments. The former of these exceptions is scarcely worth notice, as the difference is so small. The use of larger rivets with the same pitch, &c., gives an increase in the friction, but no law of increase appears to be conformed to.

"Although these experiments do not give any definite idea of the probable amount of friction which would result from the use of rivets having different diameters and pitch, they yet serve to show how much the strength of a riveted joint is increased by the contraction of the rivets."

Now, if we take the coefficient of friction of wrought iron upon wrought iron at ·18, and assume the rivets to act with the full tension of 24 tons per square inch of section in squeezing the plates together, we should require 4·3 tons weight per square inch of rivet to overcome the friction of the two surfaces. The high results obtained from the experiments were probably due to the inequalities and dirt on the surfaces of the plates in contact, which would materially increase the friction.

It must not, however, be concluded that the value of a rivet is to be determined by adding to its shearing strength the amount of friction between the plates produced by its contraction in cooling. Although these two elements of strength act together in a well-filled hole, they cannot be considered as acting independently. Whatever gain is obtained by the construction is to some extent counterbalanced by the loss of strength due to the tension on the rivet.

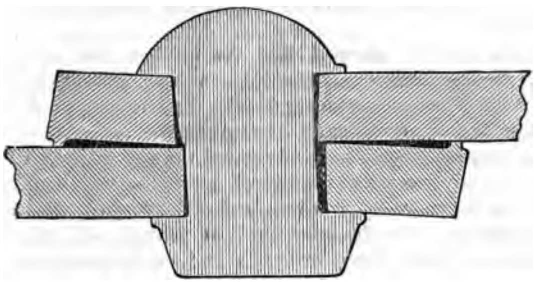
The manner in which a severe tensile strain affects a lap joint by pulling it athwart the line of strain (fig. 7, page 69), must also tend to diminish the friction of the plates. Long before the ultimate resistance of the joint is reached, especially with single riveting, the friction of the plates must be greatly diminished, and cannot be regarded as materially influencing the ultimate strength of the joint.

In old boilers it is probable that the tension of the rivet

becomes gradually eased by the continual straining and alteration of temperature, which will in time affect the nature of the iron. The friction may not, however, be diminished in the same proportion, as we may expect the contact of the surfaces to become more perfect after long wear together.

There can be no doubt that severe caulking, as commonly practised, must tend to diminish the friction between the plates, especially when they are thin. The sketch (fig. 3) shows

Fig. 3.



the manner, somewhat exaggerated, in which the plates are forced apart by the caulking, when done with a set and heavy hammer.

When the edge of the caulking tool is very thin, it is sometimes driven by careless workmen right into the joint, wedging it wide open. There should now no longer be necessity for severe caulking, since it has become the practice in all good boiler works to plane the edges of the plates. This not only leaves a better edge for light caulking, especially when it is slightly bevelled, but at the same time it enables a more uniform amount of lap from the centre of the hole to be maintained than when the edges were dressed by hand, and conduces greatly to the facility of making a tight joint.

In trying situations, where it is difficult to keep a joint tight, too much lap is decidedly worse than a slight deficiency. One and a half times the diameter from the centre of the rivet to the edge of the plate is found sufficient in every case.

Severe and careless caulking has more to answer for than is commonly supposed. On the inside of the boiler it often induces *grooving and fracture*, and even where grooving has no

existence, the fractures of the plates in exploded boilers often follow the line of caulking in preference to the line of rivet holes.

The contraction of the rivet in cooling must act transversely as well as longitudinally, and thus cause it to become slack in the hole it filled while hot. This shrinkage in the diameter is also increased by the tension due to longitudinal contraction. That the total shrinkage from these causes is very slight, is shown by the difficulty sometimes found in distinguishing the line between the rivet and plate in specimens of machine-riveted work, planed down to exhibit the quality of the workmanship.

It is sometimes affirmed that the red-hot rivet acts injuriously on the iron round the hole in hard and steely plates, especially if cooled suddenly. For this reason, and also to obviate the tensional strain caused by the contraction of hot rivets, some engineers have advocated the use of cold riveting. This certainly has the advantage of precluding the employment of all but the very best rivet iron, and of demanding that the holes shall coincide. On the other hand, it is said, cold hammering acts injuriously on the rivet-head ; and on this account, as we stated above, conical heads are falling into disuse. It is, however, questionable whether the amount of hammering that might damage bad iron would seriously affect iron of good quality.

When the length of the rivet is considerable—as, for instance, in the joint at the fire-hole and fire-box foundation rings of some locomotive and vertical boilers—the contraction in cooling often affects the strength of the rivet to an injurious degree, and draws off the head. As the contraction should be proportionate to the length of the rivet, it is not very clear why the strength is affected by the length, unless the tension is concentrated just beneath the point where the rivet remains longest hot.

Besides the shearing and stretching strains just considered, boiler rivets are exposed to other severe tests. The heads are liable to be knocked off externally by the rough usage in removing the boiler from the maker's. Inside, the heads are often detached by the careless use of hammers and picks in removing incrustation.

The jarring effect from hammering, when the boiler is undergoing repairs, frequently results in detaching brittle rivet-heads, and when exposed to the action of the fire they are liable to be

burnt, and are easily knocked off by a careless stoker. For these reasons alone, it is evident that rivets should be made of first-rate iron. Yet this is far from being the general practice, and the large quantities of rubbish that command a sale as boiler rivets is a proof of the greed, recklessness, and ignorance of the maker and purchaser of the boiler, the one being frequently no more blamable than the other.

Whilst rivets of bad iron can often be detached by a few sharp blows with a light hammer, it requires from twelve to twenty powerful blows with a quarter-hammer to force off a $\frac{3}{4}$-inch rivet-head. With indifferent iron, little or no distortion by the hammering is apparent; but with very good iron the distortion is so great that the portion of the head operated upon will be found flattened by the set, past the edge of the hole, before the iron in the shank yields.

Rivet-holes may be punched or drilled. Both methods have their partizans, who persistently maintain the superiority of the system they advocate over the other. The usual arguments in favour of punching are a saving of from one-third to one-sixth of time and labour as compared with drilling—a most conclusive argument with the manufacturer, but it does not apply so strongly when multiple drilling-machines can be used. The shape of the punched hole, which is conoidal and slightly countersunk, is considered by many to be more favourable for tight work than a hole made by the drill, which is parallel or cylindrical. There are many boiler-yards not well provided with machinery, where even the roundness of drilled holes cannot be depended upon in the haste that accompanies most of the operations in boiler-making. The punch leaves no burr behind it, as the drill does, and which should be dressed off, but is too often forgotten. When the overlapping plates are drilled together, the burr between them should always be removed, as it is liable to prevent their closing tightly to make a good joint.

It is argued in favour of the drill, that the positions of the holes marked off from the overlapping plate can be preserved more faithfully with it than with the punch. This is, doubtless, a strong argument if it can be maintained, for these half-blind holes are the bane of boiler-making. But many affirm, and with good reason, that a careful and skilful workman can punch the holes as accurately as they are likely to be drilled, unless both plates are pierced together. In some boiler-yards the accuracy of the punched holes is ensured by the use of a self-*acting traveller for feeding* in the plate. When the positions of

the holes are marked by a centre-punch, the plan is sometimes adopted of forming a very small projection on the bottom of the punch, which enables the centres of the holes in the plate to be felt for, thereby ensuring as much accuracy as can be claimed for drilling. A somewhat questionable argument in favour of drilled holes is, that the rivets are more easily removed when repairs are required. But the chief argument in favour of the drill is, that it does not injure the plates like the punch.

All kinds of boiler plates, worthy of the name, will bear punching, and in the great majority of cases without exhibiting any indications of injury from the process, when submitted to the ordinary modes of scrutiny. Yet the quality of the plate has an important influence on its manner of bearing the severe treatment it undergoes at the punching-machine. Inferior and badly refined plates, being brittle, suffer to a much greater extent than those of better and more ductile quality. In fact, punching a hole at the usual distance from the edge (one diameter clear) in an inferior ship plate will often produce fracture. It is not always the very best brands that pass through the ordeal of punching with the least injury. Some of the Best Yorkshire plates are of a hard and stubborn nature, although ductile, and possibly do not bear punching so well as some of the softer South Staffordshire irons.

There is still a want of conclusive experimental evidence to decide the precise amount of injury plates of different quality and thickness, with holes of different diameter, pitch, and distance from edge, sustain in punching. It is generally assumed that plates of fair quality, having a tenacity of 21 tons per square inch, cannot be relied upon to bear more than 16 or 17 tons per square inch of section left between holes in ordinary steam-tight riveted joints, equivalent to about 24 and 20 per cent. loss of strength. This is a maximum loss for hard plates of average boiler quality; but many soft plates do not suffer more than from 4 to 8 per cent. loss of strength with the holes punched a whole diameter clear of the edge, and at the second row of rivets in double riveting do not suffer at all. If the edge of the plate has been cut near the edge of the slab, it will be likely to suffer more in punching than if cut some distance from it. As the risk of damaging a plate by punching diminishes as the distance of the hole from the edge increases, some boiler-owners who prefer punching to drilling specify their plates to be cut about half an inch larger all round than their finished in order to keep the holes a safe distance from the edge in

punching. The surplus material is subsequently planed or dressed off.

The violence done to the plate may be seen more clearly by considering the force requisite to punch it. It has been found by experiment that the resistance of a wrought-iron plate to punching is about the same as its resistance to tearing by a tensile strain. Taking this at 21 tons per square inch, and regarding the resistance to the punch as measured, not by the area of the hole, but by the area of the metal separated, or the circumference of the hole multiplied by the thickness of the plate, we have $d \times \pi \times t \times 21 =$ force, which just balances resistance to punching a hole of diameter d through a plate of thickness t. The resistance increases directly as the thickness of plate, diameter of hole, and strength of plate, and will be affected by the condition of the punch and clearance of the die. For a $\frac{3}{4}$-inch hole through a $\frac{1}{2}$-inch plate the force required is about $24\frac{3}{4}$ tons. We can also readily find the greatest thickness of plate we can perforate with a punch of given diameter, or the least size of hole we can punch in a plate of given thickness, the compressive strength of the punch being given. Assuming this to be 100 tons per square inch, and the maximum resistance of wrought iron at 25 tons, we have the resistance of the plate $= 2\,r \times \pi \times t \times 25$, and the resistance of the punch to crushing $= r^2 \times \pi \times 100$. It is evident that when $t = 2\,r$, or diameter of hole, the two resistances are equal. We find, therefore, that when the compressive strength of the punch is just over four times as great as the tearing strength of the plate, it will just perforate a hole of a diameter equal to the thickness. If the thickness of plate be greater than the diameter of hole the punch must be stronger, or the plate weaker, than we have assumed, or the hole cannot be punched. In practice, it is rarely if ever attempted to punch a hole less in diameter than the thickness of the plate. An inch and a quarter hole through an inch and a quarter plate is what a good machine should have power to punch.

The holes are punched slightly larger than the diameter of the rivet, to allow its easy insertion when red hot. For $\frac{3}{4}$-inch rivets a bare $\frac{1}{16}$ inch in diameter is commonly allowed. This increase of diameter should obviously increase with the size of rivet. The punch should be formed slightly largest in diameter at the face, which is best made somewhat concave, rather than flat or convex, to make a clean cut. The hole in the die is always made *somewhat larger* than the punch, to lessen the

friction and to allow the wad or burr, as the piece of iron is called, to be forced out more readily than if the die were an exact fit. The less the clearance between the punch and the die, the greater the distress of the plate. The difference in size between the punch and the die is the cause of the conical shape of the punched hole. The sizes are usually in the ratio of from 1 : 1·1 to 1 : 1·2. By increasing the size of the die sufficiently the holes can be made countersunk through the whole thickness of plate. Advantage is sometimes taken of this in ship-building. The plates are put together so that the small ends of the holes are inside (fig. 4). The rivet is formed with

Fig. 4.

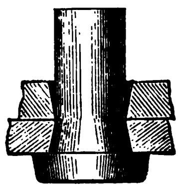
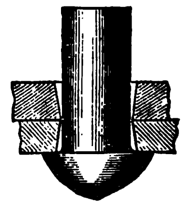


Fig. 5.



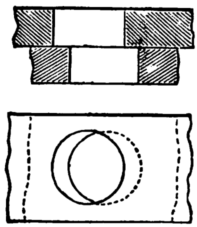
a taper next the head (fig. 4), which fills the conical hole in one plate, and the hole in the other plate is filled by hammering down the rivet. By this means the holes are more likely to be completely filled up.

It is usually understood that boiler plates with punched holes are always arranged with the holes lying together as in fig. 5, and an importance is attached to this arrangement which has, perhaps, been somewhat overrated. Where the steel drift s employed (and where is its use *altogether* dispensed with?) it will upset the edge of the hole between the plates, and separate the contact of their surfaces to a greater extent than when the larger ends of the holes are brought together, and thereby impair the efficiency of the joint. On the other hand, however, hammering up the rivet in a hole with the small ends outside tends to wedge the plates asunder. Besides, in the event of a rivet-head being accidentally knocked off, the first-mentioned arrangement of the holes will still retain the rivet in its place, and hold the plates together. The tension due to the contraction of the rivet in cooling is by this arrangement spread over the whole length of the hole, and is not concentrated at its ends. The heads have, therefore, comparatively little to do. All things

ıred, this method has its advantages, which appear to the favour in which it is held, and which outweigh any efects incidental to its employment. When repairs are d, the difficulty of getting the rivets out is about equal arrangement, if the holes are well filled and the work-p is good.

of the greatest importance that the corresponding holes ining plates should coincide, and not partially overlap ther, or be half blind, as it is called (fig. 6). In rough too little attention is paid to ıatter, and even where great ; used in marking off and ng or drilling, cases of holes inciding will frequently occur. nly do these defects add to ifficulty of making the joint by distorting the rivet and ting it from filling the hole y, but it also leads to the the drift, which in the hands

Fig. 6.



less workmen is often hammered into the hole in ı reckless manner as to cause serious injury to the With the use of the drift, which is a short steel spindle taper end, the holes are forced and contorted into an ır shape, sufficiently large to admit of the insertion of et, which passes obliquely through the plates. It will upon the degree of blindness whether the hot rivet can ımered up to fill the contorted hole or not, and make a ›int, and whether its oblique position seriously affects its to resist the strain it is designed to bear. When, as the ›f bad workmanship, the rivet cannot be inserted with-ourse to some means for straightening the holes, it is rimer them out and use a larger rivet. This has the ıge of not distressing the plate, which is sometimes sup-o be sorely enough tried in the first place by the punch-This method is sometimes employed throughout the rivet he holes being all punched or drilled somewhat less than d, and afterwards rimered to the full size. Should the ıot be drawn quite close together before the rimer is l, the particles of iron are liable to find their way be-them and impair the tightness of the joint. This plan s the conical form of the punched holes, but ensures a ob than *the ordinary* careless methods of riveting.

Several experiments have been made to determine the relative value of drilled and punched plates in riveted work.

Mr. W. H. Maynard arrived at the following results with four bars cut from the same plate, two being punched and two drilled, with 1-inch holes having the same sectional area at the reduced part—$1\frac{1}{2}$ square inches.

Breaking weight in tons.			Difference in tons.	Difference per cent. in favour of drilled.
Experiment.	Drilled bar.	Punched bar.		
1st	$30\frac{1}{2}$	26	$4\frac{1}{2}$	17
2nd	$31\frac{1}{2}$	26	$5\frac{1}{2}$	21
Mean.	31	26	5	19

The quality of the plates and the appearance of the fracture are not given, which renders these experiments of little value for deducing any general rule. The following are the results of some experiments by the same authority to test the difference in value between rivets in punched holes and similar rivets in drilled holes :—

$\frac{5}{8}$-inch rivets in drilled holes.

1st, single shear = 26 tons per square inch. Double shear = 39·2 tons.

2nd, single shear = 26·4 tons per square inch. Double shear,—Experiment failed.

$\frac{5}{8}$-inch rivets in punched holes.

1st, single shear = 27·2 tons per square inch. Double shear = 45·6 tons.

2nd, single shear = 26 tons per square inch. Double shear,—Experiment failed.

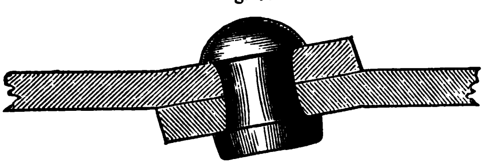
Mr. Maynard considers the above as conclusive that rivets in drilled holes, subject to shearing strain, were about four per cent. weaker than rivets in punched holes under similar strain, and thinks the sharp edges of the drilled holes have a greater tendency to nip off the rivets than the rounded edges of the punched holes. This conclusion has been confirmed by more recent experiments in America. The rivets appeared cut off cleaner by the drilled plates than by the punched.

In comparing the strength of punched and drilled work together, Mr. Maynard concludes, 1st, that drilled plates are stronger than punched by 19 per cent. ; 2nd, that rivets are weaker in drilled holes than in punched by four per cent.; 3rd, that the difference is in favour of drilled work by 15 per cent.

The above conclusions would require to be modified for different qualities of rivets, plates, and workmanship.

Sir W. Fairbairn, in his "Useful Information for Engineers," gives a detailed account of some experiment made on the strength of single and double riveted lap and butt joints, with punched holes, both snap and countersunk heads being used. The riveting was done both by hand and machinery, and, as we should expect, the latter proved the more effective. The joints with countersunk heads were found to be about as strong as the others, although there must have been a diminution of strength corresponding to the amount cut out by the countersinking. The double-riveted lap joint was found to have a strength very slightly inferior to that corresponding to the section of the plate left between rivet holes, showing the plates had not suffered materially by the punching. The single-riveted lap joint showed an average loss of strength of 24 per cent. over and above the loss due to the reduction of section at the line of rivet holes. In this case the punching may have had a more injurious effect on the plates, the line of holes being nearer the edge than the line which bears the brunt of the strain in the double-riveted joint. However, the inferior strength must be mainly ascribed to the manner in which the tension strains the joint, and draws it athwart the line of strain, as shown in fig. 7. The joint will

Fig. 7.

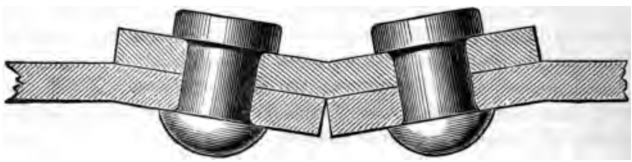


always tend to assume this form under severe tensional strain in consequence of the force tending to act in a direct line through the middle of the plates. The joint here manifestly acts at a disadvantage, the strain being unequally distributed among the fibres of the plate, those of the inside of the joint at the centre of the rivet bearing *more than* the rest. The thicker the plate,

the greater will be the unequal distribution of the stress, the leverage varying as the thickness of the plate. The same action occurs in a double-riveted lap joint, but in a much less degree, as the force acts with less angularity, and consequently more uniformly over the fibres of the iron.

The butt joint with single strip behaves in a somewhat similar manner, acting like two laps placed together (fig. 8). In the

Fig. 8.



longitudinal seams of an ordinary cylindrical boiler, this property of the lap makes itself felt very often, and results in grooving. In the transverse seams the curved form of the plates renders this distortion by the force of the steam pressure alone well-nigh impossible, but is not proof against the irresistible molecular forces, whose effects are shown in the expansion and contraction of the plates, and which cause the transverse grooving in locomotive boilers when they are secured firmly at both ends to the frame; and in stationary boilers, where the bottom is cooler than the internal tubes and upper portion of the shell.

When single-butt strips are used for the longitudinal seams, they should never be applied internally, on account of the tendency of the joint to open under pressure, as shown in the last figure. When the strip is placed on the outside, the action of the steam pressure assists in preventing the distortion of the joints.

The loss due to the unequal distribution of the tension in single-riveted joints with plates of ordinary thickness, $\frac{3}{8}$-inch to $\frac{7}{16}$-inch, may be taken at not less than 20 per cent. of the tensile strength of the material left between holes. This would leave four per cent. loss of strength in the single-riveted lap joints, tested by Fairbairn, due to deterioration by punching, and to the rivets not filling the holes so as to bear evenly on the plate, and take each an equal share of the strain. What the *loss of strength* from unequal distribution of strain may be in

strips of very thick plates, $\frac{7}{8}$-inch and above, can only be determined by actual test; it will probably amount to from 50 to 70 per cent. That the weakness of the single riveted lap joint was owing to the oblique action or unequal distribution of the strain appears to be proved by Fairbairn's experiments, where single riveting and butt joint with double strips were tried. The strength of this was found to be about equal per square inch of section to that of a double-riveted lap joint, or nearly that due to the unimpaired section between the holes.

From some experiments made by Mr. Brunel with double-fished butt joints and best Staffordshire $\frac{1}{2}$ plates, having strips $\frac{3}{8}$-inch thick, with double and triple chain and zigzag riveting, the following results were arrived at:—The sectional area of the rivets and plates should be equal: triple riveting is superior to double-chain riveting in proportion to the sectional area of plates retained; and the strength of the plates is unimpaired by the punching, 20 tons per square inch being the breaking weight alike of the solid plate and the section left between the holes.

In "Useful Information for Engineers," the strength of the joints compared with that of the entire plate is given as follows:—

Strength of plate	=	100
Strength of double riveting	=	98
Strength of single riveting	=	76

The loss of strength here given is due to the treatment the iron has received, and to the form of joint, and is quite irrespective of the diminished section at the line of rivets. A further reduction must be made, corresponding to tho amount of section removed in making the holes. This varies considerably for single riveting, but 30 per cent. may be taken as an average allowance for double riveting. Fairbairn takes 30 per cent. also for single riveting, and gives, accordingly, the actual strength of the plate and the two descriptions of joints as 100, 68, and 46. Thirty per cent. is, however, too small an allowance for single riveting, and does not agree with either the common practice or the table for the pitch of rivets given in the volume in question. This latter gives for $\frac{3}{4}$-inch rivets and $\frac{3}{8}''$ plates $1\frac{3}{4}$-inch pitch, corresponding to a loss of 43 per cent.; a loss of only 30 per cent. would require $2\frac{1}{2}$-inch pitch, which is now only very rarely employed for even very low pressure boilers. Many engineers do not avail themselves of the advantage offered by double

riveting for maintaining a large section of plate, but use the same pitch as for single riveting, the rivets being arranged in the form of an equilateral triangle, which in many cases causes the removal of 40 per cent. of section instead of 30.

Taking the average loss of material in ordinary boiler single riveting at 40 per cent., and the total loss of strength in the joint as 54 per cent., as above found, we should have therefore 14 per cent. as the amount considered sufficient for the injury caused by punching and the bad form of joint. This is too little, and should in no case be taken at less than 20 per cent., even when the plate suffers no injury by punching, riveting, &c. But taking the loss at 24 per cent., according to Fairbairn, the figures should stand as follows: 100, 68, and 36, instead of 100, 68, and 46.

These will give correctly the comparative strengths when the plates and riveted joints are broken in strips a few inches wide, as in the experiments quoted. But in a boiler very different conditions of resistance are found. Suppose a boiler shell to be made of circular belts of plate overlapping transversely, but without longitudinal joints or other source of weakness, it would then be in a condition to resist a much greater tension than the normal breaking weight of the material, in consequence of the support lent by the double thickness at the ring seams. That additional resistance is given to the plates by the transverse joints in a properly made cylindrical boiler, is evidenced by the manner in which many shells at work hold together when the whole section of a plate is cut away for a 3-foot dome hole except a strip at each end, and barely sufficient for the dome angle-iron attachment and ring seams. In such a case, and others of a similar nature, the holding together of the plate is mainly dependent upon the strength imparted by the ring seams. When the longitudinal seams break joint effectually, the ring seams also strongly resist the buckling action of the plates under strain, which we have seen, at page 69, to be such an element of weakness in single riveting. It is obvious this resistance must depend greatly upon the width of plates, and increases as the distance between the ring seams is diminished. Moreover, the circumstance alone of the longitudinal seams breaking joint, analogous to the bond in masonry, has an important influence in strengthening the shell. It is more than probable therefore that in a boiler where the longitudinal seams break joint effectually and are double riveted, the strength of the *shell is even* greater than that measured by the unimpaired

section left between the rivet holes. The resistance of this section may therefore be taken as the breaking strength of the boiler, or as a rule, 30 per cent. less than the entire strength of the plate for double riveting.

In a similar boiler single riveted, we may safely neglect the loss of strength due to the buckling action of the plates under steam, and regard the shell as being stronger than a detached narrow test strip of the jointed plates by an amount equal to 20 per cent. of the strength of the entire plate.

Taking the loss of material for single riveting at 44 per cent., the relative values will stand:

Entire plate	100
Double-riveted joint . . .	70
Single " " . .	56

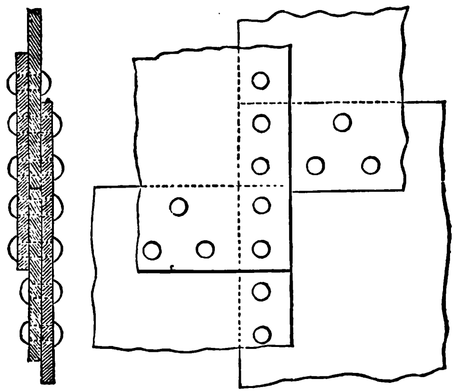
These proportions of strength are usually employed, and were originally deduced by Sir W. Fairbairn from his experiments. But in shells where the longitudinal seams run in a continuous line from end to end, we cannot count upon any gain of strength from the transverse joints. There is, however, probably a slight gain of strength in the long string of rivets as compared with a narrow test specimen, and such a shell single riveted may be regarded as having 40 per cent. of the strength of the plate.

Taking 21 tons per square inch as our standard strength for plates along the fibre, the above proportions become $14\frac{3}{4}$ tons, and $11\frac{3}{4}$ tons per square inch respectively, as the breaking strength of double and single riveted boilers having the longitudinal seams breaking joint in the proper sense of the term, and not by the amount of a rivet or two apart as in fig. 9. The table of strengths of wrought iron cylindrical boilers is calculated from the above figures. The strength of the plates across the fibre should be taken at from 10 to 15 per cent. less than the above. When the margin of safety is required to be small and plates are used of an ascertained strength of 25 tons per square inch, the strength can readily be found by adding 20 per cent. to that in the table.

In some experiments conducted at Woolwich in 1835 on different kinds of joints, the following results were obtained: for $\frac{1}{2}''$, $\frac{7}{16}''$, and $\frac{3}{8}''$ plates, the breaking strengths were respectively about 16, 17, and 18 tons for single riveted lap joints, and for double *riveted about* 24, 24 and 22 tons actual breaking

weight and not per square inch, showing that the thinnest plate was actually stronger at the joint than the thicker plates. The

Fig. 9.



inferior strength of $\frac{1}{2}''$ and $\frac{7}{16}''$ plates was probably due to the more oblique action of the strain on the joint. But for want of detailed information, the results recorded cannot be considered as suitable for deducing any general rule for the strength of plates of different thicknesses. Many have erroneously concluded from the results of these experiments that a $\frac{3}{8}$-inch plate boiler is as strong as a boiler made of $\frac{1}{2}$-inch plates. In the first place, there would be found a great difference in the strength of a $\frac{1}{2}''$-plate as a test strip and as built up in a boiler, for reasons already stated, the workmanship being equal in both cases. This difference would not be so great with a $\frac{3}{8}''$-plate. In the second place, the plate is by no means most likely to fail first through the line of rivet holes when in use. Comparing $\frac{3}{8}''$ plates with $\frac{1}{2}''$ plates, and assuming the boiler to be unfit for working at the original pressure when reduced to $\frac{1}{4}''$ thick, the latter plates will last twice as long as the former.

In seeking to determine the correct diameter and pitch of rivets, and also the proper amount of lap for different thicknesses of plate, there are several conflicting circumstances to consider. In the first place, having due regard for the economy of material it is important in fixing upon the diameter and pitch of rivets for a given thickness of plate, that the plates and

rivets should be of equal strength, for in making the rivets to fail before the plates, we should be wasting the excess of material to which is due the additional strength of the plate or be making the joint too weak. On the other hand, to make the rivets the stronger, would be to make the joint too weak by reducing the strength of the plate too much, or to waste the material in making the rivets too strong.

In the second place, the joint must be tight as well as correctly proportioned for strength. It will be seen that the attainment of the greatest strength with the least material is restricted by the necessity for tightness, and also by other minor but important circumstances.

First of all it must be ascertained in which manner the weakness of the joint may be declared. Here we find that the joint may fail in four or five different ways, namely :

1st. By the plate in front of the rivet crushing (fig. 10).

2nd. By the rivet shearing.

3rd. By the plate tearing between the rivet holes.

Fig. 10.

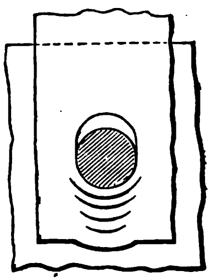
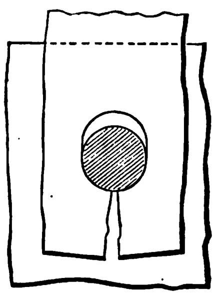


Fig. 11.



4th. By the plate outside the hole breaking through (fig. 11).

5th. By the plate being forced out in front of the rivet (fig. 12).

1st. The resistance of the plate round the semi-circumference of the rivet can be proved to be measured by the diameter of the rivet × the thickness of plate × crushing strength of plate. From the results of some experiment on the crushing strength of the bearing surface of iron links against the pins, undertaken *by Sir C. Fox*, it may be concluded that the

resistance of the plate against a rivet is equal to 40 tons per square inch, whence we have:

$$\text{resistance of plate to crushing} = d \times t \times 40. \quad (1.)$$

d = diameter of rivet, t = thickness of plate.

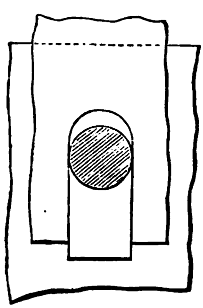
2nd. The ultimate strength of the rivet to resist shearing has already been discussed, and may be taken at 21 tons per square inch, therefore

$$\text{resistance to single shearing} = \cdot 7854 \times d^2 \times 21. \quad (2.)$$

Comparing Nos. 1 and 2, when the resistance of the rivet and plate are equal, we have

$$d \times t \times 40 = \cdot 7854 \times d^2 \times 21$$
$$d = 2 \cdot 4\, t,$$

Fig. 12.



whence the diameter of the rivet should be nearly $2\frac{1}{2}$ times the thickness of the plate. The common rule of making the diameter of the rivet double the thickness of plate up to $\frac{7}{16}$ thick is approximately correct, and allows a margin of strength for injury done to the plate in punching and drifting.

3rd. The strength of the plate between the rivet holes in boiler work, it has already been shown may be taken at 21 tons per square inch, whence

$$\text{resistance of plate to tearing} = t\,(p - d)\,21. \quad (3.)$$
where p = pitch of rivets;

comparing this with No. 2, we get for the equality of strength in rivets and plates between holes,

$$\cdot 7854\, d^2 \times 21 = t\,(p - d)\,21.$$

from which equation we can find the pitch, when the diameter of rivets and thickness of plate are given. Substituting a = area of rivet for $\cdot 7854\, d^2$ we have for a single riveted lap joint and *single fished butt joint,*

$$p = \frac{a}{t} + d. \qquad (4.)$$

For lap joints and single fished joints with double riveting, we have the sectional area of two rivets instead of one, as in the last case,

$$\text{hence, } 2\,a = t\,(p - d)$$

$$\text{and } p = \frac{2a}{t} + d. \qquad (5.)$$

In a butt joint double fished and single riveted, where the rivets require to be sheared in two places before yielding we get

$$2\,a = t\,(p - d), \text{ or the same as in the last case,}$$

$$\text{and } p = \frac{2\,a}{t} + d. \qquad (5.)$$

In a double fished butt joint with double riveting the equation becomes

$$4\,a = t\,(p - d)$$

$$p = \frac{4\,a}{t} + d. \qquad (6.)$$

In the above formulæ, d should rather be taken as the mean size of the hole than as the size of rivet, or as a rule $\frac{1}{16}$ inch larger than the rivets up to $\frac{7}{8}$ inch diameter.

When the diameter of rivet is double the thickness of plate, the pitch becomes equal to 2·57 d, 4·14 d, and 7·28 d respectively for formulæ (4), (5), and (6).

In thick plates having rivets less in diameter than twice the thickness of plate, the pitch will be less in proportion. Taking r as the ratio of diameter to thickness, the above quantities must be multiplied by $\frac{r}{2}$ for the pitch.

4. We may regard the distance between the hole and edge of the plate as the depth h, of a girder fixed at both ends, and uniformly loaded, the span being measured by the diameter of rivet, hence

$$\text{the strength to resist fracture} = \frac{t \times h^2}{d} \times C.$$

C is a coefficient, the value of which has not yet been determined. Since the nature of both the strain and the resistance differs greatly from that of ordinary girders, it is evident that we cannot consider the ordinary coefficient as even approximate. But as the coefficient is not likely to be less than the above, we may use it for the purpose of illustration We then have,

$$\text{transverse strength of plate} = \frac{t \times h^2}{d} 48.$$

Comparing this with No. 2, we have,

$$\cdot 7854 \times d^2 \times 21 = \frac{t \times h^2}{d} \times 48,$$

$$\text{when } d = 2\,t \text{ we get } h = d \times \cdot 81.$$

Assuming this to be approximately correct, it follows that the ordinary practice of making the distance between the hole and edge of plate equal to diameter of rivet gives sufficient strength to prevent the plate from breaking by a transverse strain. The greater the ratio of diameter to thickness, the less will be the proportion of lap required for adequate strength.

5. The resistance of the plate to being forced out in front of the rivet will be equal to the shearing strength of the plate multiplied by the area sheared, and may be expressed by

$$2\left(\frac{3\,d}{2}\right) \times t \times 21,$$

when the distance between the hole and edge of plate $= d$.

On comparison, the resistance of the joint to yield in this manner will be found much greater than the resistance to any of the other modes of fracture we have considered, consequently such a fracture as shown in fig. 12, is seldom, if ever, met with.

The fractures most frequently found in boiler work are those from the hole to edge of plate. They are in most cases the result of careless workmanship and brittleness of plates, except when they occur in the seams over the fire, when they are mainly produced by the contraction strain acting at right angles, and by the girder strain thrown on the plate between *the hole and edge* by the permanent contraction due to the

alternate heating and cooling. A large lap is more liable to fracture in this manner than a small one, and a thick plate than a thin one, in positions where sudden variations of temperature occur. In a line of riveted work a few holes may become fractured, or a few rivets crushed, by having to bear an undue amount of the strain, which is unequally distributed along the whole line of rivets in consequence of careless workmanship.

When the plate once yields by fracturing or crushing, it is evident that the strain will no longer be at all equally distributed along the length of plate between rivet holes, but becomes concentrated upon the fibres of the plate at each side of the rivet. The plate may then be torn in two by a force much below its breaking weight with the strain equally distributed.

The principles embodied in the above rules, based on deductions correctly made from experiments, must be accepted with some caution. In most of the experiments the plates were thin, of very good iron, and probably had not suffered much by rough treatment, which is, however, not the fate of the majority of boiler plates. Many a new boiler is set to work with the rivet holes fractured to edge of plate, or from hole to hole, by punching and drifting. Moreover, it is the practice to use a better quality of iron for the rivet than for the plate in the great majority of boilers. This lessens the chance of injury by hammering and heating, besides giving a greater tensile and shearing strength.

It may be taken as a rule that, in any but the best class of boiler work, the rivet is stronger than the plate section for section in new boilers. In old boilers the plates at the joints are generally found to be much more brittle than the rivets, and the rivets, except at the heads, will escape corrosion where the plate may suffer severely. These considerations indicate that a larger pitch than the one assigned by the rule given should be used. It must also not be forgotten that the hole is larger than the enclosed rivet, the diameter of which is usually taken in estimating the pitch. It may here be also remarked that in increasing the diameter of rivet, the pitch must be increased in a greater proportion, in order to keep the section of rivet and plate equal, for the shearing strength of a rivet varies as its sectional area, and therefore as the square of the diameter, whilst the section of the plate removed varies simply as the diameter. *It follows* from this that, the larger we make

the rivets, the better are we able to retain the gross sectional area of our plates.

The advantage to be gained by increasing the diameter of rivet is limited by the expediency of not exceeding the crushing strength of the plate in front of the rivet, which varies simply as the diameter of the rivet. It has already been shown that the plate will fail by crushing before the rivet shears when the diameter is $2\frac{1}{2}$ times the thickness of plate. It may also be observed, that by increasing the pitch we rapidly diminish the breaking strength of the plate between holes, as the increased width allows the plate to stretch more, and concentrates the strain on the fibres at each side of the hole. This fact applies most strongly to the case of double-fished butt joints, where the large pitch is necessary to bring the strength of the plate up to that of the rivets which are in double shear. It also probably accounts for the diminished strength found in experiments with riveted joints, where large rivets have been used with a very large pitch to ascertain the crushing strength of the plates. Such tests cannot be taken as a guide for the strength of joints in ordinary boiler work.

There are, however, other considerations besides the economy of material that should govern the proper pitch of rivets. A tight joint is of the first importance, for should leakage occur corrosion may soon alter any carefully calculated proportions of the respective sections in the joint. Indeed, it may be affirmed that in the majority of cases the safety of a boiler depends, in the long run, more upon the tightness than the actual strength of the joints, since a large factor of safety is usually allowed.

No one set of rules can be laid down for the pitch of rivets which shall be the best under all circumstances of pressure, quality of material, liability to corrosion, &c. The following table gives a result which agrees pretty closely with the average practice for single riveting in high pressure boilers (up to 160 lbs) if we take the proportions of diameter of rivet and thickness of plate that are given. The diameter of rivet is taken as the average diameter of the hole, and not the nett size of the rivet shank.

Single-riveted lap joints.

Thickness of plate.	Diameter of rivet.	$P=\frac{a}{t}+d.$	$P=d\times 2{\cdot}5.$	Pitch to be used.
$\frac{1}{4}$"	$\frac{1}{2}$"	$1\frac{1}{4}$"	$1\frac{1}{4}$"	$1\frac{1}{4}$"
$\frac{5}{16}$	$\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{9}{16}$	$1\frac{5}{8}$
$\frac{3}{8}$	$\frac{11}{16}$	$1\frac{13}{16}$	$1\frac{3}{4}$	$1\frac{3}{4}$
$\frac{7}{16}$	$\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{7}{8}$
$\frac{1}{2}$	$\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{7}{8}$	$1\frac{7}{8}$
$\frac{9}{16}$	$\frac{7}{8}$	2"	$2\frac{1}{8}$	$2\frac{1}{8}$
$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{1}{8}$
$\frac{11}{16}$	$\frac{7}{8}$	$1\frac{3}{4}$	$2\frac{1}{8}$	$2\frac{1}{8}$
$\frac{3}{4}$	1"	2"	$2\frac{1}{2}$	$2\frac{1}{4}$
$\frac{13}{16}$	1"	2"	$2\frac{1}{2}$	$2\frac{1}{4}$
$\frac{7}{8}$	1"	$1\frac{7}{8}$	$2\frac{1}{2}$	$2\frac{1}{4}$
$\frac{15}{16}$	$1\frac{1}{8}$	$2\frac{1}{8}$	$2\frac{3}{4}$	$2\frac{1}{2}$
1"	$1\frac{1}{8}$	$2\frac{1}{8}$	$2\frac{3}{4}$	$2\frac{1}{2}$

In the above table it will be seen that with thin plates the diameter of rivet is double the thickness of plate, and this ratio diminishes as the plates increase in thickness until with 1-inch plates the diameter and thickness are nearly equal. One reason for this is that the difficulty of making a good joint increases with the diameter of rivet where the point is not closed by an efficient machine. With 1-inch and $1\frac{1}{8}$-inch rivets heavy hammers are required to upset the iron and close the hole properly. This at once increased the difficulty of "holding up" and of making a good job. The difficulty of setting by drawing or hammering the plates quite close together to make a tight joint also increases rapidly in plates over $\frac{5}{8}$-inch thick, and altogether the quality of the work is not so reliable when very thick plates are used. Another reason for diminishing the ratio which the diameter of rivet bears to the thickness of plate is that with a constant ratio we soon reach too large a pitch to admit of keeping a tight joint, if we wish to retain anything like equality between section of plate and rivet.

With 1-inch plates, in order to retain 60 per cent. of the section of the plate whilst making the plates and rivets at the joint equal in strength we should require 2-inch rivets at $5\frac{1}{8}$ inches pitch.

Such a rivet is considered too large for closing up properly, unless with the aid of a very powerful machine, and $5\frac{1}{8}$ centres are too wide to keep tight at even moderate pressures with ordinary *workmanship.* Rivets of more than $1\frac{1}{8}$ inch diameter *are seldom if ever employed* in boiler work.

The third column in the table gives the pitch required for equal section of rivets and plate between holes. The fourth column gives the pitch required in order to retain 60 per cent. of plate at the joint. On comparing these two columns it will be seen that in plates from $\frac{1}{4}$ inch to $\frac{11}{16}$ inch thick there is no great difference between the two pitches. With the thicker plates the difference is important. The pitch for 1-inch plates in column 3 only retains 53 per cent. of the plate section, but if we employed column 4 the wide pitch would leave the rivets with only 36 per cent. of the strength of the entire plate, or about 60 per cent. of the plate between holes. Column 3 would therefore give a stronger joint than the other.

The average size of the punched hole in the plate being usually somewhat larger than the size assigned to it, and the risk of injury from punching being greater in thick than in thin plates, and also to allow for corrosion or waste at the lap, column 5 is given to work to, giving the section of the plate slightly in excess of that in column 3, and retaining about 60 per cent. of the section in plates from $\frac{1}{4}$ inch to $\frac{11}{16}$ inch thick; 55 per cent. for plates from $\frac{3}{4}$ inch to $\frac{7}{8}$ inch; and 58 per cent. for $\frac{15}{16}$-inch and 1-inch plates.

Where the workmanship is not reliable it will be advisable to reduce the pitch slightly, or to increase the diameter of rivet in plates under $\frac{3}{4}$ inch thick.

The lap for single riveting should be equal to 3 times the diameter of rivet, and never more than 3·3 times the diameter.

Double-riveted lap joints and butt joints with single strips.

Thickness of plate.	Diameter of rivet.	$P=\frac{2a}{t}+d.$	$P=3{\cdot}3d.$	Pitch to be used.
$\frac{1}{4}''$	$\frac{1}{2}''$	$2''$	$1\frac{5}{8}''$	$1\frac{3}{4}''$
$\frac{5}{16}$	$\frac{5}{8}$	$2\frac{5}{8}$	$2''$	$2\frac{1}{4}''$
$\frac{3}{8}$	$\frac{11}{16}$	$2\frac{5}{8}$	$2\frac{1}{4}$	$2\frac{1}{4}$
$\frac{7}{16}$	$\frac{3}{4}$	$2\frac{7}{8}$	$2\frac{1}{2}$	$2\frac{1}{2}$
$\frac{1}{2}$	$\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$
$\frac{9}{16}$	$\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{7}{8}$	$2\frac{3}{4}$
$\frac{5}{8}$	$\frac{7}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	$2\frac{3}{4}$
$\frac{11}{16}$	$\frac{7}{8}$	$2\frac{5}{8}$	$2\frac{7}{8}$	$2\frac{7}{8}$
$\frac{3}{4}$	$1''$	$3''$	$3\frac{3}{8}$	$3\frac{1}{4}$
$\frac{13}{16}$	$1''$	$3''$	$3\frac{3}{8}$	$3\frac{1}{4}$
$\frac{7}{8}$	$1''$	$2\frac{7}{8}$	$3\frac{3}{8}$	$3\frac{1}{4}$
$\frac{15}{16}$	$1\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{3}{4}$	$3\frac{1}{2}$
$1''$	$1\frac{1}{8}$	$3\frac{1}{8}$	$3\frac{3}{4}$	$3\frac{1}{2}$

The pitch given is along one line of rivets. The strips should be slightly thicker than the plate, $\frac{1}{16}$ inch for moderately thick plates, and $\frac{1}{8}$ inch for very thick plates. Column 4 gives the pitch, along one line of rivets, required to retain 70 per cent. of plate between holes. With 1-inch plates this would make the strength of the rivets only about 53 per cent. of that of the pierced plate. In order to obtain equal strength in plate and rivet at the joint we should require for 1-inch plates $1\frac{3}{4}$-inch rivets at $5\frac{7}{8}$ inch pitch. The difficulty is therefore obvious of obtaining a well-proportioned joint when using thick plates, with either single or double-riveted lap joints, at the same time retaining a good section of plate, and ensuring tightness. In using thick plates the best course to follow in arranging the joint is to fix upon the widest pitch consistent with tightness, employing the largest rivets admissible, and then determine the strength of the shell from the section of rivets or plate left between holes, whichever may be the weaker. In plates up to $\frac{9}{16}$ thick it is evident that 70 per cent. of section can be maintained with a well-proportioned joint and moderate pitch. For plates under $\frac{1}{2}$ inch there is an excess of strength in the rivets when using the pitch given. The diameter of rivets might therefore with advantage be slightly reduced, to make a tighter joint, for high pressures. When the boiler is double riveted throughout, $\frac{5}{8}$-inch rivets for $\frac{3}{8}$-inch and $\frac{7}{16}$-inch plates, with $2\frac{1}{4}$ inch pitch, might be used. It is, however, inexpedient to have different sized holes for single and double riveting in the same plate or boiler ; and as it frequently happens that the longitudinal seams of a boiler are double riveted, whilst the transverse seams are only single riveted, the same sized rivets have been used in making the above tables.

The greatest difficulty in making a well-proportioned joint with the same sized rivets occurs when butt joints with double strips and lap joints come together in the same plate. In such a case we must either sacrifice the advantage of having the same sized hole throughout the plate, or have a badly proportioned joint in one seam or the other. On this account, when double-fished butt joints are used in the same plate with lap joints, the former may be made single and the latter double riveted; in which case the same pitch and diameter of rivet might be judiciously employed, were it not for the difficulty of keeping a tight joint in the butt arrangement, which necessitates the reduction of the pitch, unless the workmanship is very good.

The double-riveted lap should be equal to 5 times the diameter of rivet, each line of rivets being $\frac{3}{8}d$ from the edge of plate.

Double-riveted butt joints with double strips.

Thickness of plate.	Diameter of rivet.	Thickness of strip.	$P=\frac{4a}{t}+d.$	$P=3\cdot3d.$	Pitch to be used.
$\frac{3}{8}''$	$\frac{5}{8}''$	$\frac{1}{4}''$	$3\frac{3}{4}''$	$2''$	$2\frac{1}{2}''$
$\frac{7}{16}$	$\frac{5}{8}$	$\frac{1}{4}$	$3\frac{1}{8}$	$2''$	$2\frac{5}{8}$
$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{16}$	$3''$	$2''$	$2\frac{3}{4}$
$\frac{9}{16}$	$\frac{11}{16}$	$\frac{5}{16}$	$3\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{7}{8}$
$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{8}$	$3\frac{1}{2}$	$2\frac{1}{2}$	$3''$
$\frac{11}{16}$	$\frac{3}{4}$	$\frac{3}{8}$	$3\frac{3}{8}$	$2\frac{1}{2}$	$3\frac{1}{8}$
$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{16}$	$4''$	$2\frac{7}{8}$	$3\frac{1}{4}$
$\frac{13}{16}$	$\frac{7}{8}$	$\frac{7}{16}$	$3\frac{3}{4}$	$2\frac{7}{8}$	$3\frac{1}{2}$
$\frac{7}{8}$	$1''$	$\frac{1}{2}$	$4\frac{1}{8}$	$3\frac{3}{8}$	$3\frac{5}{8}$
$\frac{15}{16}$	$1''$	$\frac{1}{2}$	$4\frac{3}{8}$	$3\frac{3}{8}$	$3\frac{3}{4}$
$1''$	$1\frac{1}{8}$	$\frac{9}{16}$	$4\frac{5}{8}$	$3\frac{3}{4}$	$4''$

In double-riveted butt joints with double covering strips, it will be seen from the annexed table, on comparing columns 4, 5, and 6, that we cannot avail ourselves of the full strength of the double riveting when the rivets are in double shear, and must be content with 75 and 70 per cent. of section of the entire plate with thin and thick plates respectively. Smaller rivets than $\frac{5}{8}''$ should not be employed, unless they are made with much larger heads than is the custom, in order to withstand the effects of corrosion. On account of the difficulty of obtaining sufficiently strong punches smaller rivets than those given for the thick plates cannot be recommended. Where the holes are drilled this objection does not apply, and a different table may be arranged, commencing with $\frac{1}{4}''$ plates as they stand and ending with $1''$ plates having $\frac{7}{8}''$ rivets at $3\frac{1}{4}''$ pitch.

Besides the loss of strength due to the unequal distribution of the strain through the whole thickness of the plates in a lap joint, very thick plates are also liable to be much reduced in strength through the body of the plate by injury done in the excessive amount of setting they require where the transverse and longitudinal seams cross each other. For this reason alone *butt joints should* always be used at least for the longitudinal

seams with plates over $\frac{5}{8}''$ thick. The width of the strip for double riveting should be at least 9 times the diameter of rivet, and may, with thick plates, be made equal to 10 times the diameter, the distance from the centre of the holes to edge of plates and strips in all cases being equal to diameter of rivet multiplied by $\frac{3}{2}$.

CHAPTER V.

WELDING.

THE numerous purposes to which wrought iron is applied could not be effected without its valuable property of welding. It is of the utmost importance that the effect of this process on the strength of the material should be properly understood, since there are more structures depending on the soundness of the weld than on the strength of the rolled or forged bar or plate.

Mr. Kirkaldy made some experiments on the breaking strength of welded bars. The results varied greatly, showing a loss of from 2·6 to 43·8 per cent., the mean loss being 20·8 per cent., compared with the solid bar, the fracture taking place in most instances partly through the solid bar and partly through the weld. The loss of strength in four "Farnley" 1-inch square bars varied from 6 tons to 9¼ tons, the original strength averaging 28 tons per square inch. With 14 "Glasgow Best Best" bars, varying from 1¼ inch to ¾ inch square, the loss of strength varied from ¾ tons to 11 tons, per square inch, the average loss being 8 tons. The original strength was, on an average, about 25½ tons per square inch.

Mr. Kirkaldy found that in heating a bar of Glasgow B. Best iron to the welding point, and then allowing it to cool slowly, that the breaking strain was nearly the same as that borne by another piece off the same bar in the ordinary condition; but the ductility of the iron was injured by the high temperature and want of hammering.

Several experiments to determine the strength of welded plates have been made, and have given satisfactory results. Of these may be mentioned the trials at Woolwich on the strength of plates welded by the Bertram process, recorded by Mr. D. K. Clark.

The joints were of two descriptions, namely, the scarf weld and the lap weld. The tensile strength was found to be

20 tons per square inch for the solid plates, $\frac{1}{2}$, $\frac{7}{16}$, and $\frac{3}{8}$ inch thick. Taking the strength of the entire plate at 100, that of the scarf weld for the $\frac{7}{16}$ and $\frac{3}{8}$ plates was respectively 106 and 102. The $\frac{1}{2}$-inch weld proved faulty. The results from the lap weld, as might be expected from the unequal distribution of the strain at the joint, were not satisfactory, being respectively 50, 69 and 66. This makes the absolute strength of the two lap welded joints alike for $\frac{1}{2}$- and $\frac{3}{8}$-inch plates, the $\frac{1}{2}$-inch plate having only $\frac{1}{3}$ of the strength of the entire plate, whilst the $\frac{3}{8}$ plate has $\frac{2}{3}$ the strength, which may be accounted for by the more unequal distribution of the strain with the thicker plate. The meagre information respecting the fractures, and the fewness of the tests with each variety of weld and thickness of plate detracts very much from the value of these experiments as a standard for general use.

Mr. Kirtley, in a paper read before "The Institute of Mechanical Engineers," records the results of some experiments on the tensile strength of strips of plate cut across the weld, which were taken from several boilers made with welded longitudinal seams. The strips were in three sets, $7\frac{1}{2}$ inches long, the weld being in the middle of each piece. The following table gives the results of the tests; the plates were $\frac{7}{16}$ inch thick:—

Strength of welded plates.

Width of strip.	No. of strips tested.	Broke in weld.	Broke in solid.	Breaking strength in tons per square inch. Least.	Greatest.	Mean.
1"	15	8	7	16·5	23·8	20·2
$1\frac{3}{8}$	4	2	2	19·6	22·2	21·0
$1\frac{1}{2}$	4	1	3	18·1	23·5	21·7
Total	23	11	12	16·5	23·8	20·6
Also 11 strips of the same plates unwelded.				20·7	25·8	23·6

It appears from these results that half of the test pieces broke in the solid, and not at the weld.

The average *loss of strength* of the 23 welded plates was

only 12·7 per cent., compared with the strength of the 11 unwelded plates, the worst pieces showing as defective a weld as would occur in practice had 70 per cent. of the average strength of the unwelded plates.

The weld is best made when the edges of the plates are upset, at a red heat, by hammering or pressure, to nearly double their thickness, and bevelled to an angle of about 45°. The edges can then be heated simultaneously, and the weld made by hammering down the joint to the original thickness of the plate.

CHAPTER VI.

CONSTRUCTION OF BOILERS.

SINCE the plates are stronger lengthways than crossways, they are generally arranged in a cylindrical boiler shell, with the fibre running circumferentially, in which direction they are best disposed to resist the greatest strain due to the internal pressure. But owing to the greatest strain in externally fired boilers being along the bottom in a longitudinal direction from the sudden contraction caused by a rush of cold air, or by the delivery of cold feed water on to the bottom plates, some engineers prefer to arrange the plates with the fibre running lengthways along the boiler. By this arrangement the bottom plates are also more easily replaced, a circumstance of some importance with hard-worked externally-fired boilers, in which the furnace plates require frequent renewal. In order to avoid the great inconvenience and sometimes danger from the constant fracturing of rivet holes, especially in the transverse seams over the fire, it is best to make the furnace plates of externally fired boilers sufficiently long to keep the first ring seam away from the influence of the entering cold air, and at the same time to set the boiler so that the end seams do not become intensely heated. This arrangement necessitates the use of a very large furnace plate, since the width must be sufficient to keep the longitudinal seams also out of reach of the fire and entering cold air, which have a much less effect on the single than on the double thickness of plate that occurs at the lap joints.

In short boilers, such as many of the useful little vertical class, the plates are most easily arranged in one length, with their fibre in the direction of the height of the boiler, thus saving the work in one ring seam. In all such cases where the plates are arranged lengthways along the cylinder, it is advisable to allow a greater margin of safety than when the plates are arranged lengthways round the cylinder.

Wherever a ring seam occurs the longitudinal seams should be made to break joint, for the sake of obtaining the increased strength due to this arrangement. This necessitates the thinning away of the inside plate corners where the overlap occurs. In order to avoid the labour that this involves, which is considerable when thick plates are used, the plates are very often arranged to break joint by one or two rivets only, as shown in fig. 9, page 74. This arrangement is but little stronger than having the seams in one line, from end to end, and should never be used. It however saves the hammering that thick plates with lap joints have to undergo to make them fit at the ring seams, where the longitudinal seams break joint, which must in many cases damage the iron considerably, and to avoid this, as well as the unequal distribution of strain involved by the use of the lap, the longitudinal joints at least should be made with double butt strips, in using thick plates.

The courses or belts of plates that make up the length are usually arranged conically in stationary boilers, with the outside lap facing backwards. When the boiler is set slightly inclined towards the front end, this arrangement of the plates facilitates the draining of the water and sweeping out at the boiler bottom towards the front, where the dirt is usually removed. This advantage is greatest in internally fired boilers, which are difficult to clean. In externally fired boilers this arrangement of the ring seams saves the edges of the plate from the direct impingement of the flame, which takes place when the outside laps face the front. It is, however, more liable to interfere with the free contraction of the shell on the brickwork, which acts from front to back, and which is of more importance than freedom of expansion, the former being more sudden than the latter.

In long vertical boilers it is customary to arrange the ring seams with the inside lap facing downwards, so as not to leave a projection for the incrustation to lodge upon. With the same object in view, some engineers also insist upon the longitudinal seams at the sides of locomotive boiler shells being arranged with the edges of the top plates inside, as they consider the liability to groove is increased when the edge of the inside plates face upwards, to form a ledge for the incrustation to accumulate upon.

In locomotive boilers the belts of plating are nearly always arranged parallel, and of late it has become the practice with many makers to arrange them telescopically with the largest

diameter at the firebox end, to which the sludge is drained for removal at the mudholes. This arrangement also allows room for a slightly wider firebox ; it also facilitates the arranging of the tubes, and, in many cases, tends to prolong the life of the firebox.

Of late years it has become the practice with the best makers to use larger plates in the shell than formerly. In stationary boilers the size is usually limited by the weight the manufacturers supply the plates at, without extra charge, which, as a rule, is 4 cwt. for plates of good Staffordshire quality. The greatest width, without extra charge, is usually about 4 feet, and the length is arranged to keep the weight of the plate within 4 cwt. ; but many engineers wisely prefer to incur the extra cost of using larger plates, and so reduce the number of seams and consequent risk of lèaky joints and rivets as well as of grooving. Locomotive boiler barrels are frequently made with plates long enough to necessitate only one longitudinal seam in each belt of plates, which should be placed above the water level, where it is not liable to groove. In some cases the longitudinal seams are welded, and the ring seams made with outside covering strips. In order to still further increase the strength of the boiler where there are no external flues, strong wrought-iron rings are shrunk on at mid-length of each belting. To compensate for the strength lost by cutting out the rivet holes, plates with thickened edges are sometimes used for locomotive boiler barrels. As the thick edges are in the direction of the length of the plate, they can, unfortunately, only be used for the ring seams where the additional strength is least required in well-designed locomotive boilers.

The strength of the cylinder and sphere has already been examined, and the resistance of flat and cambered surfaces partially discussed. In boilers of even moderate diameter, and under ordinary pressures, the flat ends of ordinary thickness are so weak, if unstayed, that the bulging out would be excessive, and would consequently tend to act with a considerable leverage, and wrench off the rivet heads securing the plate to the barrel, if attached in the ordinary manner by angle irons. The alternate bulging and straightening of the plate produced by the varying pressure in the boiler would also tend to produce fracture through the line of rivet holes, or work open the fibres of the iron along the line where this action is most felt, and which is generally along the inside edge of the angle iron, or at the *angle iron root,* producing leakage, grooving, and,

ultimately, fracture, which are treated of in the chapter on "Wear and Tear."

It may be here remarked that the mode in which a flat, dished or cambered end plate is secured to the barrel materially affects its capability of resisting the effect of the internal stress upon it. The modes adopted are by angle iron, either internal or external, or by flanging either the barrel or end plate.

Where stiffness is not required near the circumference of the barrel, as, for instance, where it is desirable to leave room for the plate to spring, in the case of internally fired boilers, the angle iron should be applied outwardly, or the barrel flanged outwardly, to receive the end plate.

As a rule, the flanged arrangements are less liable to grooving than when angle irons are used, and form the best mode of attachment, provided the plates are not too much reduced in thickness when the flanging is outward. In Cornish and Lancashire boilers, it is the custom to attach the front end plate with outside angle irons, and the back end with inside angle irons. The crowns of vertical boiler shells are usually attached by flanging or by inside angle irons. Where, however, in long boilers the internal flue tubes are not more than 5″ or 6″ from the side of the barrel, outside angle irons should be used to allow the end-plate to spring.

In small vertical boilers sufficient strength can be given to the end-plate by dishing it, which removes the necessity of staying it further than with the flue tube. In cases where there is a cluster of small tubes, the crown is best made flat for facility of tightening the tube ends, and in most cases sufficient strength can be given to this plate by increasing its thickness within moderate limits.

With a view to strengthen the furnace crowns of small vertical boilers, they are usually made with considerable camber. In many cases, however, this camber renders the plate too stiff and unable to spring without producing grooving; a certain amount of play should be allowed, in order to accommodate the expansion and contraction of the flue tube or tubes.

Various methods have been devised for securing the internal furnaces of vertical boilers to the shell. The first that suggests itself is the old-fashioned solid ring, made out of a rectangular bar of iron. The depth of this ring should never be less than its width, as the pressure on the crown has a tendency to upset it. When the ring is shallow, the upsetting action frequently produces grooving in the shell plate, round the top of the ring. When

these rings are more than 3″ wide, and of equal depth, they should be double riveted, to prevent leakage and grooving, if they have to carry a great load. There are more than half-a-dozen other methods, but which do not call for remark.

We shall now consider the various means used to strengthen flat and cambered surfaces, such as screwed and riveted bolts, stiffening ribs, girder stays, gussets, &c.

The difference in strength between screwed and unscrewed bolts, according to Mr. Kirkaldy, is influenced by the manner in which the dies act upon the iron. Old dies have a hardening effect, which raises the breaking strength at the expense of the stretching, when compared with new dies or chasing tools, which cut cleaner. The average tensile strength of a screwed bar, 1″ and above in diameter, may be taken at 20 tons per square inch of the unscrewed section. It has been frequently assumed that bolts of small diameter—$\frac{5}{8}$″ or $\frac{3}{4}$″, are superior in strength, section for section, to those of $1\frac{1}{4}$″ and above; but recent experiments do not bear out this assumption—at least, not to the extent asserted, some 50 per cent.

In order to preserve the original strength of a tie bar, as well as to facilitate the operation of screwing it into the plates, it is customary to increase the diameter of the screwed portions. This also acts advantageously in allowing the bar to stretch when strained severely. A bar of ordinary quality and of uniform section throughout is found, under tension, to stretch considerably before breaking. The degree and regularity of the stretching depends principally upon the quality of the material. If, however, the section of the bar be diminished in one or more places, the effect of the strain and consequently the stretching is confined to these weaker portions, so that a bar with a narrow groove, like the thread of a screw, cut in it, scarcely stretches at all before breaking. It is for this reason that screwed tie rods, without swelled ends, are sometimes found to snap suddenly under severe strain, usually at the end of the screwed portion to which the stretching is confined. When the ends are thickened for screwing, so that the diameter at the bottom of the thread exceeds that of the rest of the bar, the stretching is no longer confined to one part, and the bar is better able to bear a sudden strain.

The practice of turning the thread off the middle portion of locomotive firebox stays, or of swelling the diameter of the screwed ends, is sometimes adopted to render the stays more *flexible, and consequently* better able to bear without

injury the awkward transverse strains thrown upon them by the greater expansion of the inside firebox compared with that of the outside shell, which, in course of time, renders the iron stays in the upper parts of the box exceedingly brittle and liable to snap. Another advantage claimed for this plan of turning off the thread is that the even surface of an iron stay withstands the corrosive action of the water better than when it is screwed. For durability the stays of locomotive fireboxes are better made of copper, especially those that are in contact with the mass of incandescent fuel. With firebox plates not more than $\frac{7}{16}''$ thick, the thinnest part of the stay, or the diameter at the bottom of the thread, should not be less than $\frac{3}{4}''$ when copper stays are used, or else they are liable to bend in hammering down the ends. This applies to stays even as short as 3″ between plates. With stiffer stays of iron the smallest diameter may be $\frac{5}{8}''$. On the other hand it is not advisable to make these iron stays larger than $1\frac{1}{8}''$ outside diameter, with $\frac{7}{16}$ plates, as the extra amount of hammering involved in knocking down the ends of thicker bolts, with ordinary care, is liable to spoil the threads.

In using water containing certain salts, the use of copper stays is sometimes accompanied by a rapid corrosion, which appears like countersinking of the inside of the iron plate round the bolts. This is usually ascribed to galvanic action. The heads of copper stay bolts should, in consequence, be made larger than is the usual practice, as, too often, little or no thread is left to depend upon.

For plates less than $\frac{3}{4}$ inch thick, the number of threads on the bolts' stay should not exceed 11 or 12 to the inch, in order to get a good hold when screwed into the plate. When the stay is not screwed into the plate it is usual to secure the ends with nuts and washers, which should be applied to both sides of the plate, to insure tightness or freedom from leakage. The thickness of the nut is usually made equal to the diameter of the screw. This allows a margin of strength to compensate for badly formed and loose threads. It has been found that where the thickness of the nut and diameter of the screw are as $\frac{3}{4}$ to 1, threads of ordinary pitch, if well made, and a good fit, will not strip before the bolt breaks.

Besides being screwed into the plate and having the end riveted over, or passed through the plate and secured by nuts and washers, longitudinal and other stay bars, which may be *either square* or round, can be secured to flat plates by means

of pins, bolts, or cotters passing through angle irons or T irons, which impart stiffness to the plate they are riveted to. The practice of securing them by cotters and saddle plates is not so common as it was a few years ago. When pins or bolts are used they should always be arranged for double shear, either by forming double eyes upon the ends of the stay which clip the T iron, or by forming a single eye on the stay and placing it between two angle irons through which the pin passes.

In proportioning the sizes of the stay bar and its bolt so that they may be of equal ultimate breaking strength, the diameter of the bolts will usually be too small to afford sufficient bearing surface in the angle or T iron, which, except in locomotive boilers, seldom exceed $\frac{5}{8}''$ in thickness, and soon fail by crippling or bulging. In order to increase the bearing surface on the angle iron and at the same time to impart additional stiffness to the structure, $\frac{1}{2}''$ or $\frac{5}{8}''$ plates about $6''$ wide are frequently riveted to these end angle irons in stationary boilers. Instead of using a very large single bolt to ensure sufficient bearing surface, it is better to forge a good deep T end upon the stay bar, which can be secured to the angle irons between which it is placed by three or four bolts of moderate diameter.

A defect often met with in staying the ends of boilers is the omission of cotters through the pins when double eyes and single T irons are used. This omission allows the double eye to open out under strain, when it acts upon its pin with considerable leverage and bends it. These pins are sometimes found bent to an angle of 90° and totally inoperative. When the stay is secured by cotters and saddle irons care should be taken to make the cotter of sufficient depth, since it is usually by its bending that this system fails. The hole through the saddle plate should not be cut larger than is absolutely necessary to let the stay pass, which is usually square.

When the flat surface is of small area and the pressure is not great, stays or tie bolts are sometimes dispensed with, and stiffness is imparted by simply riveting angle or T irons to the flat plates. These are disposed radially or in which ever manner they can best be applied to take the strain, according to circumstances. This mode of strengthening the ends of cylindrical boilers is very inefficient, and is unfortunately but too often employed. Numerous cases have occurred where it has been the source of much annoyance and loss. It is used chiefly by makers to *save expense*, or by those who have experienced

trouble from grooving and other evils caused by an injudicious application of gussets or other stays.

It is sometimes argued that if the ends be prevented from bulging by stiffening ribs, any further staying to the shell or from end to end is superfluous, as the rivets securing the end to the shell are sufficient of themselves to prevent the end from being torn off. This argument can, however, only apply to a new boiler, for it is found that the ever-varying strains to which the flat surfaces of boilers are subjected, often in the course of time seriously affect the strength of these stiffening ribs however well they may have answered at first. Cases have occurred where T iron ribs on the ends of internally fired boilers have become crippled with the working pressure after a few years' use, and yet showed no permanent set when the boiler was tested by water at double the pressure when new. In the cases referred to, the T irons were not injured by corrosion, which would have caused them to fail much sooner. The loss of strength can only be ascribed to the injurious effect of the continually varying strain.

The circumstance appears to be sometimes overlooked that the pressure against a flat end plate merely stiffened and not stayed, exerts an awkward strain on the rivets and heads attaching it to the shell angle iron, and a trying transverse strain on the plate at the line of attachment, in consequence of which plates strengthened in this manner often fail from tearing through the line of rivet holes.

It is only in cases where the diameter of the boiler is very small, or the pressure very low, that stiffening ribs are to be recommended. In some instances they can be advantageously applied as auxiliaries to longitudinal and gusset staying.

In boilers of considerable length, say 20 feet and upwards, it is necessary to support or suspend the longitudinal stays, and unless they are secured by nuts at one end at least, they should be divided at mid length and provided with a double socket and two cotters to draw them taut. It is of the first importance that the arrangement of longitudinal staying should not interfere with the efficient cleaning or examination of the inside of the boiler. But in too many cases the stays are made so small in section and consequently many in number as to render it quite impossible to reach all parts of the boiler. For facility of cleaning and examination as well as for efficient staying, gussets should be used in preference to any other method for *strengthening* the flat ends, unless the boiler is of such small *length* compared with the diameter as to render the application

of efficient gussets as great an impediment to cleaning as longitudinal staying.

In all cases where single gusset plates are used they should be secured to the shell and ends by double angle irons with the rivets in double shear, and not by single L irons or T irons with the rivets loosely inserted and acting with scarcely any effect. Double gusset plates and T irons are not to be recommended owing to their greater expense, when single plates and double-angle irons can be made to do as well. Some makers set and fix their gussets to the shell before the end plate is attached. This enables the gusset to be made of one plate. When, however, the gussets are applied subsequently to the fixing of the end plates, they require to be made in pieces sufficiently narrow to admit of their introduction through the manhole. The former of these methods requires greater skill to make a good job, but forms a better stay than the latter. When the stay consists of a single gusset plate, and where its length and strength of attachment on the shell side is sufficient to resist the tendency of the strain to move it in a longitudinal direction or to turn it on a point near the corner formed by the end plate and shell, it will fail by crippling at the rivet holes, or by shearing the rivets securing the plate to the end, or by drawing off the rivet heads securing the angle irons to the flat end, which must therefore be made sufficiently strong to bear the strain where most severe, which will be at the centre of gravity of the sector when the gusset is arranged radially.

When the stay consists of a gusset plate and diagonal plate, the strength of the latter must be considered separately as a diagonal stay. It may, however, be remarked that a considerable portion of the strain that would otherwise come upon the diagonal plate is distributed by the angle iron over a portion of the gusset plate; and where the edges of the two plates are also butted well together the whole stay may be considered as a solid gusset plate.

There can be no doubt that where applicable a gusset forms the best stay, especially in cases where it is of great depth, which enables it to act effectively over a great length of plate. In the event of the end plate giving way through the rivet holes or along the edge of the angle iron securing it to the boiler shell or flue tubes, the gusset plate if well secured would be more likely than any other kind of stay to hold the end plate in its place and allow the pressure to diminish gradually through the rent formed, instead of blowing the plate completely away and causing a violent explosion.

In cases where considerable pressure is used, it is advisable to extend the length of the gusset along the shell and secure it to the second belting of plates, and not to the first only, which is the usual practice. Long, plain, cylindrical externally fired boilers being liable to break their backs, should have their ends tied together with stout longitudinal plate or bar-stays properly suspended or supported where necessary. These stays are not so much intended to prevent the occurrence of transverse seam rips as to prevent the two ends flying off in opposite directions if a transverse rent should occur, and so far are meant to prevent an explosion, or at least to greatly mitigate its effects.

Straight furnace tubes attached by angle irons or flanges to flat plates and small tubes riveted over at the ends may be regarded as stays for the plates they unite. When, however, in the case of a cluster of small tubes the plates are thin and of large area the tubes alone cannot be depended upon, even when ferruled and riveted over at both ends, and their efficiency as stays should be increased either by prolonging some of them beyond the plates and screwing nuts on their ends, or by inserting at proper distances longitudinal stays secured by nuts both inside and out.

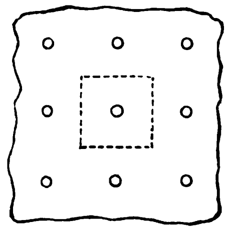
It must be remembered that in longitudinal tubes heated internally either all round their circumference when vertical, or only on their upper surface when horizontal, the greater expansion of the tube compared with that of the shell, throws a severe strain on the end attachment and stays, over and above that due to the pressure. This happens only with tubes of too large a diameter compared with their length to accommodate themselves to the expansion by bending, and it is only after the expansion due to the heat has been allowed by the bulging of the end plate or stretching of the shell and stays, that the tube can be regarded as a stay at all. It is, therefore, obvious that such tubes should have freedom to expand and contract without throwing undue stress on the rest of the boiler, which is best effected by imparting to the end plates the least amount of rigidity consistent with safety, which may be done by keeping all the stays the greatest distance allowable from the tube, and by making the flat ends as thin as may be expedient.

The flat ends of tubular boilers, at least up to 8 feet diameter, should always be made in one plate, either solid or welded, and not in several pieces, which are so liable to leak or groove at the riveted joints.

The usual method of calculating the pressure acting on stay

bolts, is to consider each bolt as sustaining the pressure against a certain area of the plate to which it is attached. In water-space staying the area is measured by the rectangle contained between four bolts, as in fig. 13.

Fig. 13.



Where the pressure is very great, as in locomotive boilers, the strength of the plate is not taken into account, the whole pressure being regarded as borne by the stays. Water-space stays should be made to bear at most one-eighth or one-tenth their breaking strain, or say 4000 lbs. per square inch, to ensure sufficient strength being left when they are wasted by corrosion. The whole surface of the stay bolt is exposed to the corrosive effect of the water, whilst only one side of the plate is exposed.

The size of the stay may be found by the following formula :—

$$A = \frac{s^2 \times P}{4000}$$

where A = area of each bolt ; s = distance between centres, and P = working pressure.

When the area of the bolts is given, the distance of the centres can be found as follows :—

$$s = \sqrt{\frac{4000 \times A}{P}}$$

In determining the diameter of stay, it is usual to make it twice the thickness of the plate.

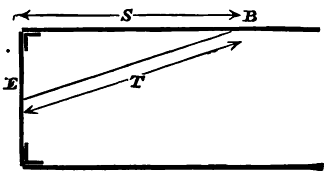
To render the inside of locomotive and similar boilers more accessible, the end plate stays are sometimes arranged diagonally and secured to the shell, and in various other descriptions of boilers diagonal stays are used instead of longitudinal. These diagonal stays should never be attached to the inside furnaces or furnace tubes, where they are liable to cause trouble by their tendency to arrest the expansion and contraction of the plates. The resultant tension is greater on a diagonal than on a longitudinal stay, and may be found thus :—

$$D = \frac{P}{\text{cosin } A}$$

F 2

where D = tension on diagonal stay ; P = pressure against end plate, and A the angle which the stay makes with the direction of the pressure against the flat plate.

Fig. 14.



In fig. 14, if we make S the distance between the flat plate E, and stay attachment B = the pressure at right angles to the plate which is supported by the stay, the tension D will be represented graphically by the centre line T of stay.

We are indebted to Sir W. Fairbairn for some experiments on iron and copper screwed stay bolts, let into copper and iron plates similar to locomotive firebox staying.

1st. A $\frac{3}{4}''$ iron stay with enlarged head screwed and riveted into a $\frac{3}{8}''$ iron plate, failed by breaking through the shank with 12·5 tons, the screw and plate remaining uninjured.

2nd. A similar arrangement, but with a copper plate, failed with a load of 10·7 tons, the head tearing off, and the copper threads stripping.

3rd. A $\frac{3}{4}''$ iron stay with enlarged end screwed into a $\frac{3}{8}''$ copper plate, and not riveted, was drawn out of the plate by 8·1 tons, the copper thread stripping.

4th. A $\frac{3}{4}''$ copper stay with enlarged end, screwed and riveted into a $\frac{3}{8}''$ coppper plate, broke through the shank with 7·2 tons, after stretching $\frac{9}{16}''$.

The above results may be arranged as follows :—

	Breaking weight. Tons.	Strength distributed over 25″ area, this would give lbs. per square inch.	Strength distributed over 16″ area, this would give lbs. per square inch.
1st. Iron into iron, screwed and riveted . . .	12·5	1120	1750
2nd. Iron into copper, screwed and riveted . . .	10·7	960	1500
3rd. Iron into copper, screwed only	8·2	726	1134
4th. Copper into copper, screwed and riveted . . .	7·2	645	1008

The first of these results shows that $\frac{3}{8}''$ length of screw, supplemented by a riveted head, is fully equal in strength to the bolt.

Comparing the second and fourth results, we find that an iron stay is 50 per cent. stronger than the copper stay, both being in copper plates.

The method of locomotive firebox staying was still further tested by the same eminent authority. Two boxes were constructed, each 22″ square, having $2\frac{3}{8}''$ water space between $\frac{3}{8}''$ iron and $\frac{1}{2}''$ copper plates, stayed with $\frac{13}{16}''$ iron stays, having enlarged ends screwed into the plates, and riveted. In one box the stays were arranged at 5″ centres. On the application of water pressure the sides began at 455 lbs. per square inch to bulge outwards between the stays. At 815 lbs. the construction gave way, the head of the central stay being drawn through the copper plate. In the other box the stays were placed at 4″ centres. The bulging began at 515 lbs., increasing to 995 lbs.; from this to 1295 lbs. the increase of the bulging was inappreciable; it then increased till the pressure reached 1600 lbs., when it amounted to one-third of an inch. At 1625 lbs. the $\frac{3}{8}''$ iron plate gave way by the thread stripping, and allowed one of the stays to be drawn through.

In this last experiment the iron plate and not the copper one was the weakest, whilst the stays remained sound. The greatest stress upon each stay was 9 tons for those at 5″ centres, and $11\frac{1}{2}$ tons for those at 4″ centres. The actual breaking strength of the stays would be about 16 tons.

Comparing these last results with the first of the other set of experiments, we find the thread in the iron plate 14 per cent. weaker under conditions approaching nearer to those in actual practice than obtained in the experiment when the plate stood sound at 12·5 tons. The bulging of the plate may account for the decrease of strength, as it would cause the plate to be drawn away all round the screw, especially on the inside, and would therefore diminish the efficiency of the threads. With a similar box, but having the stays at 9″ or 10″ centres, it is very probable the bulging would be so great as to enlarge the holes, and allow the centre stays to draw out without even stripping the threads.

Whatever value the above experiments may have in proving that for similar arrangements the bolt is weaker than the plate, and that the usual practice of locomotive firebox staying is sufficiently strong, they afford no sufficient data on which to

base the ultimate strength of the plates themselves, as for instance when the stays are better secured by nuts and washers instead of by riveting over. For want of better information we are still justified in proportioning our stayed surfaces according to the theory advanced on page 23—that the strength of flat stayed surfaces is inversely as the square of the distance of the stays, the thickness being constant, and with the same distance of stays the strength of the plate varies as the square of the thickness, and may be expressed by the following formula :—

$$P\, s^2 = 2\, c\, h^2$$

where P = pressure, s = distance between stays, c = a constant, which we may take at 54,000 for iron plates, h = thickness of plate. If we take 6 as the factor of safety, c becomes 9000.

When the pressure and thickness are given, we have,

$$s = \sqrt{\frac{2\, h^2\, c}{P}}$$

from which formula the following table of distances of stays for different pressures with $\frac{3}{8}''$ $\frac{7}{16}''$ and $\frac{1}{2}''$ plates is calculated.

Pressure in lbs. per square inch.	Centres of stays for		
	$\frac{3}{8}''$ plates.	$\frac{7}{16}''$ plates.	$\frac{1}{2}''$ plates.
20	$11\frac{1}{4}$	13	15
30	$9\frac{1}{4}$	$10\frac{3}{4}$	$12\frac{1}{4}$
40	8	$9\frac{1}{4}$	$10\frac{5}{8}$
50	$7\frac{1}{8}$	$8\frac{3}{8}$	$9\frac{1}{2}$
60	$6\frac{1}{2}$	$7\frac{5}{8}$	$8\frac{3}{4}$
70	6	7	$8\frac{1}{8}$
80	$5\frac{5}{8}$	$6\frac{1}{2}$	$7\frac{1}{2}$
90	$5\frac{1}{4}$	$6\frac{1}{5}$	7
100	5	$5\frac{3}{4}$	$6\frac{3}{4}$
110	$4\frac{3}{4}$	$5\frac{1}{2}$	$6\frac{3}{8}$
120	$4\frac{1}{2}$	$5\frac{1}{4}$	$6\frac{1}{8}$
130	$4\frac{3}{8}$	5	$5\frac{7}{8}$
140	$4\frac{1}{4}$	$4\frac{7}{8}$	$5\frac{5}{8}$
150	$4\frac{1}{8}$	$4\frac{3}{4}$	$5\frac{1}{2}$
160	4	$4\frac{5}{8}$	$5\frac{1}{4}$
Dia. of stay	$\frac{7}{8}''$	$1''$	$1\frac{1}{4}''$

As the unstayed surfaces are calculated from the centres of the stay bolts, instead of from the edge of the head or actual point of support, the above table gives a greater margin of safety than 6, and the centres may be increased $1\frac{3}{8}''$ for $\frac{3}{8}''$ plates; $1\frac{1}{2}''$ for $\frac{7}{16}''$ plates, and $1\frac{3}{4}''$ for $\frac{1}{2}''$ plates. The strength of the bolts must be increased to correspond with the increase of surface; and instead of the sizes given at bottom of the table, they will vary from 1 to $1\frac{1}{4}$, from $1\frac{1}{8}$ to $1\frac{3}{8}$, and from $1\frac{3}{8}$ to $1\frac{5}{8}$ respectively for pressures of from 20 to 160 lbs. The increased distances can only be relied upon where the stays are secured by nuts, or where these are not admissible, by strong, stout, riveted heads, not liable to waste away, and not where the paltry flat heads so generally used are employed.

As, however, $1''$, $1\frac{1}{8}''$ and $1\frac{1}{4}''$ are for $\frac{3}{8}''$, $\frac{7}{16}''$ and $\frac{1}{2}''$ plates respectively, the largest diameter of stay that admits of having proper sized heads formed by hammering, without injuring the threads, these diameters should limit the widest centres of stays, when nuts are not used, at different pressures, which may be found by the formula already given at page 99.

$$S = \sqrt{\frac{4000 \times A}{P}}$$

It may be remarked that the centres of stays in locomotive fireboxes are seldom determined by the thickness of metal or pressure, $4''$ centres being the general rule for firebox staying, whether the pressure be 100 lbs. or 180 lbs., or the plates be $\frac{5}{16}''$ or $\frac{5}{8}''$. The centres in this case are determined chiefly by the capability of the copper plates in the furnace to resist bulging when they become over-heated, which often happens, especially when the water is bad.

The above experiments of Fairbairn were made on plates and stays at an ordinary atmospheric temperature, and cannot therefore be taken as a standard for the strength of copper plates in a firebox. In treating of the properties of copper, it was stated that its strength diminished rapidly with an increase of temperature, some experiments having shown that 25 per cent. of its tensile strength was lost at a temperature of 500°. When the water is very bad, there can be no doubt that the temperature of the plates rises considerably above this. This circumstance accounts for $\frac{3}{8}''$ and $\frac{1}{2}''$ copper plates stayed at $4''$ centres sometimes failing after two or three years' work, under a pressure of from 100 lbs. to 140 lbs. The character of the

failure varies in an unaccountable manner; sometimes the plates are rent for a considerable length in a straight line between two rows of stays, and in some cases, especially when the stays are wider apart than usual, or about 6", the bulged plate gives way at its apex, the course of the rent being diagonal to the stays. The position, also, of the rupture varies in different cases. Frequently the crown plate gives way first, which may be accounted for by the deposit from the water settling on this plate. When the water is very bad, the partial choking up of the side and end water spaces, particularly when they are cramped, impedes the free ebullition of the water, and overheating, as in the other case, ensues.

The flat crowns of locomotive and portable boiler fireboxes, and of combustion chambers, are not usually directly stayed to the outer shell, like the ends and sides of the fire-boxes, but are strengthened by stay bolts and nuts suspended from wrought-iron girder stays, which should be bedded firmly on the tops of the end or side plates, but by preference on the former. These girder stays are either forged solid, or they are made of two plates, with a space between, for the bolts, and are riveted together at the ends. To avoid having an undue thickness of metal, as well as to preserve a water way for circulation, and cleaning out, a clear space of at least $1\frac{1}{2}$ inch should be left between the roof plate and girder stay. In order to enable the stay bolt to be tightly screwed up, without bending the plate, it is the usual practice to insert ferrules between the plate and stay. Another plan is to forge projections on to the solid stay bottom, which serve as distance pieces, and into which the stay bolts are tapped from the under side. Both these methods act also with advantage in imparting great strength and stiffness to the whole. The plate is thus made to act as a bottom flange to the girder, and is fixed at the ends, whilst the web is merely supported at both ends. The girder is therefore of a compound type. For want of sufficient experimental data from which to deduce a rule for the strength and stiffness of this arrangement, we must confine our attention to the strength of the stay itself, using a smaller factor of safety in consequence of the strength imparted by the bottom flange. The stay may then be taken as a beam, uniformly loaded, and supported at both ends. Its strength can therefore be determined by the usual formula,

$$\frac{W\,l}{8} = \frac{c\,b\,d^2}{6}$$

Where W = distributed weight, = pressure × distance between girders × length of span = $p \times S \times l$

l = length of span in inches.

c = modulus of rupture = 54000.

b = breadth in inches.

d = depth " "

p = pressure in lbs. per square inch.

The length of span being given as well as the pressure and width between girders, the breadth and depth are the unknown quantities usually required. The breadth varies from $\frac{1}{3}$ to $\frac{1}{5}$ the depth, and may be taken at $\frac{1}{4}$th, which is about the average. Taking the factor of safety at about 3, the formula for the depth becomes

$$d = \sqrt[3]{\frac{P \times Sl^2}{6000}}$$

In girder stays of long span one-fourth the depth will be found too much for the thickness, and may be made one-fifth, the depth being increased to correspond.

As wrought-iron bars under a transverse strain deflect considerably before they break, the useful strength of wrought-iron girder stays must be estimated by the amount of deflection it is safe or expedient to allow, and not by their actual breaking weight. It has been found that in bars, whose depth is not less than about one-tenth their length, the deflection due to a load less than that required to overcome the limit of elasticity, or about one-third the breaking weight, is trifling, and when the strength is proportioned accordingly the bar may be regarded as sufficiently stiff.

When a girder stay of known proportions has been found to answer under a certain pressure, it is sometimes useful to know how its stiffness is affected by the alteration of pressure, or of its proportions. The conditions of stiffness are shown by the following formula:

$$\frac{l^3 W}{b d^3 \delta} = c$$

l = length of beam, b = breadth, and d = depth,
c = a constant quality, and δ = deflection.

From this it is seen that the deflection of a beam is directly as the weight *and cube of* the length, and inversely as the

breadth and cube of the depth. In order to preserve the same stiffness, the depth must be increased in the same proportion as the length, the breadth remaining constant. With a constant depth the stiffness will remain unaltered when the breadth is as the cube of the length, or when $b^{\frac{1}{3}}$ is as l.

The usual method of staying firebox crowns by girder stays has the disadvantage of causing half the load on the crown plate to be concentrated upon a few portions of the end plates. With a large firebox this load is frequently more than that required to crush the copper and produce distortion of the tube holes. In order to avoid this and the great size of the stay, necessary in very long fireboxes, if arranged longitudinally, the girder stays are sometimes arranged transversely. In whichever manner these stays are placed, too great care cannot be taken to make them sufficiently long, and to bed them firmly and evenly on the end or side plates, in order that the weight may come directly on to these, and be carried by the foundation ring of the firebox instead of by the roof plate, which is sometimes the case when the censurable plan is adopted of not letting the girder stay ends project past the ends or sides, but merely to rest on the crown plate, thus throwing the weight on the joints, or portion of the roof that is ill calculated to bear the strain.

In order to relieve the foundation ring of the great strain that would otherwise be thrown upon it, some of the girder stays are usually secured to the outer shell crown by sling stays attached to angle or T irons.

A plan of arranging the girder stays, adopted to a considerable extent on the continent, is to carry them right across the firebox crown, and secure them firmly to the outside shell sides, which must be carried sufficiently high to admit of this arrangement. The formula for calculating the strength of these stays is that for beams uniformly loaded and fixed at both ends.

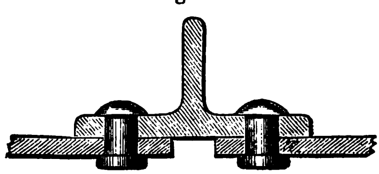
Another arrangement is to fix the girder stays in a longitudinal direction to the outer shell crown. In this case the stays usually consist of plates secured by angle irons to the shell, with double-angle irons below, to which the firebox crown is stayed by bolts in the usual manner. This and most of the arrangements of girder staying interfere greatly with the washing out and cleaning of the crown, which rapidly wears out in consequence. In order to obviate this defect, and at the same time to get rid of the cumbrous weight and mass of these heavy

stays the practice is becoming now more general of staying the fire-box crown to the outer shell like the sides and ends. The outer shell crown plate is in some such cases made flat, which renders the attachment of the stays more easy, and allows the outside plate to spring, and so accommodate itself to the expansion and contraction of the firebox, to which it is now rigidly attached. Where the outer shell is circular the stays require to be arranged to allow sufficient play at the ends of the inside crown for the vertical expansion and contraction of the side and end plates.

In order to preserve the cylindrical form, the tubes in the best made Cornish and Lancashire boilers are welded at the longitudinal joints when made of iron. In using steel and where the workmanship of the welding cannot be relied upon in iron tubes, butt joints with strips on the water side should be used. These longitudinal seams in the furnace plates should in all cases be kept below the fire bars, whether the joint be lap, butt, or welded. Steel tubes are usually considered stronger than iron in the ratio of 6 : 5. The usual means of strengthening furnace tubes by dividing them into short lengths is to join each belt, or every second or third belt, according to the strength required by T-iron rings, "Adamson" ring seams, or "Bowling" hoops.

In using the first method (fig. 15) which imparts great (sometimes too great) rigidity to the tube, the flange in contact with the tubes should not exceed the thickness of the plate, or say $\frac{3}{8}''$ as a rule, but the perpendicular flange may be made stronger. By making the successive belts of plate to butt closely together, a practice which is still sometimes stupidly adopted, too great rigidity is imparted to the tube, and grooving on the water side at the edge of the T-iron flanges is sure to follow. Owing to the difficulty of effectually caulking such a joint, either in a single or two-flued boiler, when a leakage occurs at the water spaces, it cannot be stopped, and the tube must be eventually replaced by one of better design. In order to ease the tube, and to allow of efficient caulking at any time, which can be done all *round the tube* on the fire side, a clear space of at

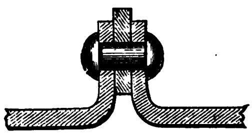
Fig. 15.



least 1″ between the plates should always be allowed, as shown in fig. 15. This also lessens the liability to overheat at the seam by keeping down the thickness of material. To make a good job by this mode of strengthening, accurate workmanship is required, as the two lengths of tube which are embraced by the same ring should be of exactly the same diameter, or the joint will give trouble.

A better means, however, of strengthening than the above is the Adamson or flanged seam (fig. 16), which has long been used with success. It necessitates the use of good iron in the first place to ensure sound flanging, which is, however, sometimes not skilfully done, and the plates are seriously reduced in thickness at the edge. In many boiler works this flanging is economically done by suitable machinery in one or two heats, which ensures a better job being made, and distresses the plate less than the repeated heating with the common method, an advantage of vital importance when steel is the material to be operated upon. The strip of plate between the flanges is used rather to admit of sound caulking from the fire side, than to add strength. The root of the flange should not have too small a radius, say not less than $\frac{5}{8}''$ in the inside, or the plate will be liable to become grooved on the crown by the alternate expansion and contraction, the allowance of which is one of the advantages claimed for this seam. The grooving of the flange, which frequently takes place, especially at the end attachment, is easily repaired by riveting over it a piece of thin plate. Not the least important advantage in this seam is that it keeps all the rivet heads and plate edges away from the fire, which renders it eminently suitable for a furnace joint. The pressure inside the boiler also tends to keep the joint closed. When any defect requiring repairs occurs at the joints, either to the plates or rivets, in the narrow water spaces at the sides of or between the tubes in Lancashire boilers, or at the bottom of Cornish boilers, the inaccessible position renders repairing very difficult.

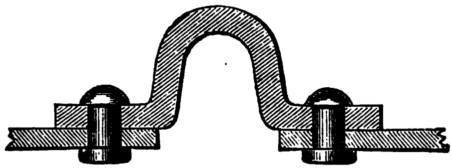
Fig. 16.



The bowling hoop (fig. 17) in iron or steel is of more recent date, and has not been so largely applied as the other two methods. Its shape precludes the objection of too great rigidity, *but like the* T-iron hoop, it has the disadvantage, when used

to connect the furnace plates, of placing a joint, along with a double thickness of plate in the fire.

Fig. 17.



Another method of strengthening tubes consists in making the contiguous belts that make up the tube of two different sizes. The ends of the smaller belts are flanged to a ⅂ shape to receive the larger lengths, and these flanges impart strength to the tube.

It has also been proposed to strengthen tubes by making them of corrugated plates, the corrugations running at right-angles to the axis of the tube.

In many second-rate boiler works, instead of using any of the above means for strengthening the tubes, it is a common practice to apply one or more welded or jointed T or angle iron hoops (figs. 18 and 19), secured to the tube plates by rivets, which should not be more than 6″ centres apart.

Fig. 18.

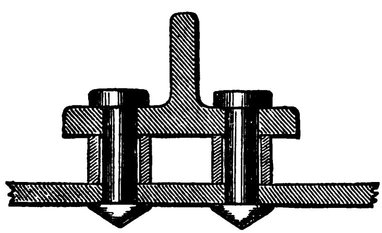
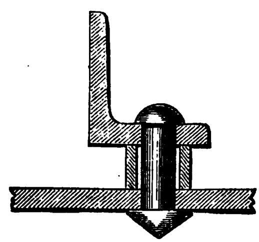


Fig. 19.



In order to avoid overheating by having an undue thickness of metal, about an inch water space is maintained between the hoop and the tube by means of ferrules, as shown. As these have no duty but to act as distance pieces they are best made very light, and everything should be done to keep the space as *clear as clear as* possible to avoid overheating. With this

object in view, T iron hoops should never be employed. Their extra strength is totally unnecessary, and their increased width acts injuriously in preventing the escape of the steam from the tube surface, and in harbouring the incrustation and deposit to a greater extent than the narrower L iron flange. The usual size of angle is from $3'' \times 3''$ to $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{2}''$. A section of $3'' \times 2\frac{1}{2}'' \times \frac{3}{8}''$ might, however, be used with advantage. This would be found quite strong enough, and much lighter than the sections usually employed.

These strengthening rings are frequently found riveted to the body of the plate, without any water spaces at all, or with the water space so small as to be practically worthless, the circulation of the water and removal of the accumulated dirt being entirely prevented. The result of this practice is overheating, the effects of which are unmistakably exhibited in cracked rivet-holes and consequent leakage and corrosion.

It frequently happens that strengthening hoops require to be added to boilers already in use, or after their construction is completed. In such cases angle irons should be used, and in order to get them through the manhole they require to be made in halves. In putting these round the tubes their ends should be carefully butted together, and secured by double fish-plates, with at least two rivets at each side of the butt. They can then be secured to the tubes with rivets passed through light ferrules, about one inch deep, and at not more than 6″ centres. In Lancashire boilers, with very narrow middle and side water spaces, the perpendicular flange often requires to be cut away to clear the shell or the other tube, and care should be taken that it clears properly when put on and when the boiler is at work, and also that the incrustation does not effectually bind it to the shell after working some time. The corresponding hoops on the flues of Lancashire boilers should be placed two or three inches clear of each other. When these hoops come in contact with the shell or with each other, they interfere with the free action of the tubes, which frequently leads to leakage, fractured rivet holes, and started seams.

There can be no doubt that the "Adamson" seam is the only one whose principle recommends it for the furnace end of a tube where the joint is unavoidably exposed to the action of the fire, and it should be applied in all new boilers to the furnace, whether the collapsing strength of the tube requires it or not. *However* liable to cause slight overheating the angle iron hoop *may be, it sh*ould nevertheless be applied round the furnace,

to all unstrengthened tubes in use, as a precaution against a collapse on a large scale, in the event of the furnace crown becoming overheated.

Cylindrical, conical, oval, and rectangular water-tubes are often used as a means of strengthening boiler flue tubes of both cylindrical and elliptical section. Where the side and middle water spaces are very small in Lancashire boilers, these water tubes are preferable to encircling hoops, as they offer at the same time one of the best means of improving the general circulation of the water in the boiler, which is always defective when the water spaces are less than 4″, even with a clean shell. To facilitate their application to boilers in use water tubes are sometimes with advantage fixed in a sloping direction fore and aft in the tube. The Galloway tube, however, offers the greatest facilities of application, besides being the best in shape for promoting the circulation.

Where several water tubes are applied as means of strengthening a cylindrical flue tube, they should be arranged vertically, and inclined sideways to break joint, but never quite horizontally, or in one line from end to end. When water tubes are used behind the bridge, the furnace itself, when cylindrical, should still be strengthened by an encircling hoop, to prevent a serious collapse, as already observed. The ends of water-tubes should always be flanged for new boilers. Angle irons only add to the risk of leakage, but may in some cases be used with advantage in old boilers, as they facilitate the application of the tube. Some boiler-makers weld-in their water-tubes to avoid leakage from joints or rivets. No doubt the motive is good, but when the tube requires cutting out for replacing, the welded part also generally requires to be removed, and causes a very large hole to be made in the flue tube.

Water pockets in the sides of the flue tubes are also employed to a considerable extent, instead of water tubes passing through the centre. They certainly have the advantage of allowing a freer passage along the tube for cleaning and examination than ordinary 5″ or 6″ water tubes, which are often injudiciously applied only three or four feet apart to tubes of even less than 2′ 3″ diameter, and prevent the passage of any but a very small adult; the cleaning in consequence becomes neglected, and the reduction in the evaporative speed and economy of the boiler inevitably follows.

CHAPTER VII.

BOILER MOUNTINGS, ETC.

THE subject of boiler mountings may be fitly introduced by a few remarks on their proper mode of attachment, which is too often overlooked.

The first object to be sought is a good joint, which will ensure freedom from leakage, and its accompanying evils. At the flat ends and flat surfaces, which can be readily dressed up to form a good face there need be no difficulty in making a tight cement joint, by bolting the mountings directly on to the plate, provided that the plate is not liable to bulge by the pressure, and the flange to be bolted is not too thin, and the studs or bolts are not too few and far between, and not too small to admit of the nuts being tightly screwed up. The proportion between the stiffness of the flange and the number and size of bolts employed is a simple consideration too frequently not sufficiently considered.

On a curved surface, however, like a boiler-barrel, or hemispherical end or dome crown, an ordinary cement joint with bolt studs cannot be depended upon for tightness. In all such cases the mounting should be attached to a seating securely riveted to the plate. This seating may be suitably made of cast iron, from a pattern tried on to the curved surface. When the aperture in the plate is not of the roughest description, a good joint with the plate can be ensured by caulking from the inside. But in order to provide against any uncertainty in the fit of the casting, and to enable the joint to be caulked on the outside, it is sometimes recommended to interpose a layer of sheet iron about $\frac{1}{8}''$ thick between the casting and the plate. With careful workmanship and ordinary skill this refinement is not necessary.

In certain cases seatings of wrought-iron, brass, or cast-copper, admitting of caulking inside and out, are applied with

advantage. The surface of the seating, which receives the mounting, being flat in all cases, can be truly faced and a perfectly tight joint insured.

The form of the seating admits of some little variety, and may be left to individual taste and judgment.

The application of riveted seatings is rendered doubly necessary when the attachment to the plates is concealed from view by brickwork or other covering. Yet they are often objected to on the score of expense. The outlay, however, in many cases would be far better applied in providing suitable seatings than in attaching a dome, which in the great majority of cases is an useless and cumbersome appendage.

Where the mounting is attached once for all, there need be no difficulty in making a faced joint tight with a thin film of cement. But in cases where the joint is periodically broken and remade, as, for instance, at the manhole, the faces are liable to become uneven from rough usage, and the perfect tightness is no longer easily obtained. Cement being no longer proof against leakage, resort must be had to cord, india-rubber, copper wire, or what is sometimes found to answer better than anything with rough faces, namely a piece of $\frac{3}{8}''$ or $\frac{1}{2}''$ lead pipe carefully arranged, with the ends overlapping within the circle of bolts. An excellent plan of making a tight joint is to cut a semi-circular $\frac{1}{4}$-inch groove in each of the two faces, into which a copper wire is inserted, with the ends brazed together, and sufficiently thick to keep the faces from close contact when the joint is screwed up. The faces of manhole and mudhole-mouthpieces are often destroyed by attempts to wedge off the covers when these are difficult of removal. The reckless insertion of chisels, &c., may be avoided by providing two tap-bolts at opposite points on the cover. On screwing these up against the face of the seating the cover is gently but irresistibly removed.

THE FEED APPARATUS.

Every boiler should be provided with its own independent feed back pressure valve. In too many cases reliance is placed upon the pump valves and the check valve, fitted to some injectors for preventing the water being forced back out of the boiler by the steam pressure. Now, in the case of a single boiler the pump valves may be considered as a sufficient safeguard *against the loss of* water by the way it entered, if

there be no way of escape between the boiler and the pump. But it so frequently happens, during the life of a boiler, that branches are added to the feed delivery pipe terminating in a stop valve, or tap, which requires to be closed and opened by hand, whereby a great risk of emptying the boiler is incurred, that it is advisable to fit a check valve to every new boiler in the first instance. With respect to the check valve on a Giffard's injector, its action cannot be depended upon, as it is usually inverted, or, at the best, placed horizontally. Boiler feed check valves should never be placed horizontally, as, when the closing of the valve is not assisted by its own weight, the back pressure of water from the boiler often fails to make it act.

When two or more boilers are fed from the same pump, it is necessary that each should be furnished with a back pressure valve. The system, but too common, of providing each boiler merely with a stop valve for regulating the feed has led to numerous explosions, from the water being syphoned out of one boiler into the other. The presence of a stop valve between the pump and boiler should always be accompanied by a relief valve, to prevent risk of bursting the delivery pipe by closing the stop valve with the pump at work.

There are two descriptions of feed back pressure valves in general use, viz. : ball clacks, and mitre valves with feather guides. The casing may be made of cast iron, but the valve seat and lid must be of brass, or rather gun-metal. Ball valves are usually employed in locomotives, as they act more freely, are less prone to stick fast, require less frequent renewal, and are generally more suitable for the high speed of pump attained in locomotive working. Mitre valves are also sometimes used for locomotives, especially with injectors, and nearly always for stationary boilers, where they are readily adapted to act also as stop valves, by having a spindle made to screw down on the valve lid, by which the amount of lift can be regulated. A common but dangerous practice is to have this spindle attached to the valve. By this arrangement its closing can be prevented, and it is thereby rendered non-self-acting and useless for a back pressure valve.

Two common defects met with in the design of back pressure valves are, 1, the allowance of too much lift, which quickly brings about the destruction of the valve and seat, so far as tightness is concerned, by the hammering action they undergo, *especially* with a quick stroke pump. 2. The delivery branch *to the boiler* is often not kept sufficiently high above the valve,

and the chamber above the valve is not made sufficiently large. This, causing the back pressure to act on the side of the valve, instead of on the top, leads to the unequal wear of the seat, if it does not actually prevent the valve from closing properly. These two defects, which often escape detection, have been the cause of endless trouble in keeping these valves tight. One quarter-inch left is as much as any valve should have, and in many cases $\frac{3}{16}''$ lift should not be exceeded. The average rate of flow through the valve is 400 feet per minute, and should not exceed 600 feet. In order to diminish the blow on the valve, an air vessel is sometimes added, and also a valve for the admission of air on the suction side of the pump. To save the pipe from bursting, it is obvious that the size and lift of the pump valves should be governed by those of the check valve.

A great diversity of opinion exists respecting the best position for the introduction of the feed water. The usual practice is to admit it near the bottom in all kinds of boilers. Whether this is theoretically correct with a view of obtaining the maximum evaporative efficiency depends upon the description and arrangement of heating surface. There are, however, practical considerations which completely overrule any supposed or actual saving of fuel to be derived from introducing the feed at the lowest point of the boiler. When the water enters at a very high temperature the results obtained from difference of position will of course be less marked.

In externally fired boilers the usual plan is to carry the feed pipe from the crown down to within a few inches of the boiler bottom, which receives the impact of the cold water. The natural tendency of this mode of delivery is to lower the temperature of the plates in the vicinity of the feed pipe orifice every time the water enters, thus increasing unnecessarily the wear and tear of the boiler. When the feed is not heated, and the plates on to which it is delivered are exposed to a high temperature, this practice is simply dangerous, and is one of the most frequent causes of transverse seam rips. Even with feed water at a high temperature, say 250°, the difference between this and the temperature of the plates may still be very great.

When the pipe is cut short, say two feet from the bottom, the injurious effect of the entering water is no doubt diminished, but, even in this case, when the supply, sufficient to serve half-a-dozen boilers, is concentrated for a time on a single boiler, the water must be *injected* with great force upon the plate

beneath. A plan frequently adopted to prevent the cooling effect on the plates is to fix a vessel under the mouth of the pipe to receive the feed. By this means the water is also better distributed, as it overflows by displacement from the sides of the vessel. With some waters this vessel may be made to act usefully as a sediment collector.

In Cornish, Lancashire and similar boilers, the feed is usually delivered near the bottom, either through an aperture in the front end plate, or through a vertical pipe from the crown, or by the bottom blow-out pipe. This practice appears to be due to the prevalent opinion that by delivering the cold feed at a high point in the boiler the furnace crown seams are liable to be started, and that the cold water should be admitted as far below the steam as possible, to prevent any condensing effect it might produce. In multi-tubular boilers of the locomotive type, the feed is admitted at various points in the firebox and barrel according to the practice prevailing in different localities.

Now, in most internally-fired tubular boilers there is a considerable amount of dead water at the bottom which remains comparatively cold long after steam is being formed above where the heat is greatest, and it seems opposed to common sense to prolong the existence or increase the quantity of this dead water by admitting the cold feed at the bottom, where it has a tendency to remain. By introducing it at a higher point in the boiler, the comparatively cold water naturally tends to descend, in consequence of its superior gravity, and promotes the circulation by displacement. In its descent, which may be retarded by the circulation, the water becomes heated, and thus tends to equalise the temperature above and below, and thereby lessens the inequality between the temperatures of the top and bottom of the shell, which is so destructive to the boiler.

Another circumstance in connection with this matter, which is too often lost sight of, is the importance of preventing as much of the water as possible from being forced back through the feed inlet, in the event of the back pressure valve not acting properly—by no means a rare occurrence brought about by defective condition, or by the obstruction caused by chips or pieces of incrustation lodging on the valve seat. This consideration alone should go far to determine the best point for the feed delivery, and consequently in the best boiler practice the feed apparatus is arranged to deliver an inch or two below the lowest water level. By this arrangement the furnace crowns

of internally fired boilers, and the hot side plates of externally fired boilers, are not liable to be suddenly drained dry in the event of the feed-check-valve becoming inoperative. In order to guard against any risk of starting the furnace-tube seams of internally fired boilers, the feed should be admitted through a horizontal perforated pipe, having the end closed, from four to eight feet long, placed just below the lowest water level. By this means the water is well distributed, and can have no sensible effect in contracting the plates. By making the internal feed-pipe of considerable length, an opportunity is afforded of raising the temperature of the entering water before it mixes with the water in the boiler.

In using feed water containing much bicarbonate of lime in solution, the elevation of temperature causes such a rapid precipitation of the lime salts, that the perforations become rapidly choked up, which leads to serious inconvenience. With water of this description, it is advisable to use a short internal pipe, only a few inches in length, ending in an open trough, or pipe of larger diameter with the upper side cut away. The distribution of the water is by this means still maintained, whilst the liability to choke up is to a great extent removed.

In the locomotive class of boiler it is difficult to apply any internal feed arrangement, and experience has proved that from the difficulty, and, in many cases, the impossibility, of frequent examination, it is safer to leave them off, in consequence of their liability to choke up with deposit. The same remark applies with almost equal force to small vertical boilers internally fired. A short pipe, delivering just below the water level, can in all cases, however, be attached to the feed-valve, and arranged so as not to inject the water against the furnace plates or tubes. The feed inlet should never be placed near the tube plates or firebox plates in locomotive boilers, since the contraction produced by the impingement of the cold feed is sure to make the tubes leak, if it does not crack the plates. This applies also to cases where an injector is used for feeding, notwithstanding the high temperature at which the feed is introduced. When the feed-valve is placed on the shell crown of horizontal boilers, the vertical pipe should be provided with a perforated T-pipe end, attached so that it can be easily removed for cleaning. In internally fired boilers the feed valve is best placed on the side of the front end plate, where it is most accessible.

When placed on the shell crown, the valve should be workable from *the boiler front by* means of gearing suitably arranged

to be within reach of the fireman at his post near the furnace door and water gauge. The feed supply should always be regulated to keep the water level as nearly stationary as possible. This can usually be easily managed when the demand for steam is regular. It is far better for the boiler than the careless but common practice of allowing the water level to fall periodically a few inches and rapidly raising it by turning the feed full on. The rapid introduction of a large body of cold water frequently causes leakage at the rivets and joints, and increases greatly the wear and tear of the boiler, not only by suddenly contracting the plates, but also, indirectly, by reducing the steam pressure, and necessitating heavy firing, which again gives trouble by the priming it causes.

It is very important that the feed water should be introduced into the boiler at as high a temperature as possible, both with the view of maintaining an even temperature throughout the boiler, so as to reduce the wear and tear arising from unequal expansion and contraction, and also to effect a direct saving in fuel when the feed is warmed by the exhaust steam or waste gases. The mode of estimating the saving to be effected by any increase in the temperature of the feed is given on page 308. It may be remarked that the value of an efficient apparatus for heating by the waste gases is greatest when it is used in connection with boilers badly proportioned or badly set, which allow a great waste of heat up the chimney.

The feed-water may be heated in various ways. In condensing engines it is usually supplied from the hot-well, where the temperature is usually about 100°. In non-condensing engines it may be heated with the exhaust steam, either by surface or injection. The usual plan for heating by surface is to force the water from the pump to the boiler through a spiral or serpentine coil of pipes, enclosed in a suitable casing, through which the exhaust steam passes. Another plan is to let the exhaust escape through one or more pipes surrounded by a narrow annular space, through which the feed is slowly forced into the boiler. The objection to all effective surface heaters by exhaust steam is their liability to become furred up when the water contains a considerable quantity of lime-salts, the deposit of which rapidly diminishes the efficiency of the apparatus, and may in course of time prevent the passage of the water altogether, unless the pipe is sufficiently large to admit the formation of a coating thick enough to keep down the temperature of the water below the point of precipitation.

The usual plan of heating by injection is to carry the exhaust pipe into an open or closed tank containing the water to be heated, upon the surface of which the current of steam is directed. By regulating the influx of the cold water the temperature of the water in the tank can usually be maintained at the boiling point. The water may be heated both by the exhaust steam and the waste gases, by suitably arranging the annular chamber round the exhaust so as to receive the heat from the escaping gases. The most effective plan of heating by the exhaust is to allow the water in the form of spray to fall from the top of a vessel through the ascending current of steam. Where but little grease is used in the cylinder, and the water is good, heating by injection can be used with great advantage, but where the water contains much carbonate of lime or magnesia, the presence of these salts, in combination with the grease, leads to leaky joints, fractured rivet holes and bulged plates, and other effects of overheating,

There are various plans for heating the feed by the waste gases. The water is sometimes led through a coil of pipes placed in the smoke-box or external flues. These apparatus are usually very efficient at first, when they are arranged across the current of gases, but their efficiency rapidly diminishes as the pipes become coated with soot and flue dirt, which usually happens unless the surface of the pipes is kept clean by continual scraping. With an efficient apparatus in contact with the gases escaping at between 600° and 700°, the feed may be heated when the boiler is at work to 250° or more.

In heating by exhaust steam from a non-condensing engine the feed can at the best only be raised to the boiling point corresponding to the barometric pressure, or to a temperature of about 212°.

Since nearly all heating apparatus are liable to derangement from furring up, and from joints or pipes breaking in inaccessible positions, it is advisable to have a duplicate and reliable direct communication between the pump and the boiler in cases where the stoppage of the boiler for a few hours is attended with great inconvenience.

SAFETY VALVES.

The safety valve should be large enough to allow all the steam that may be formed in the boiler to escape with sufficient rapidity to *prevent the initial* blowing-off pressure being ex-

ceeded by more than about 12 per cent. The quantity of steam generated will depend upon the amount of fuel consumed, and the amount of water evaporated per lb. of fuel in a given time. These quantities are again dependent upon the size of fire grate and rate of combustion, and upon the quality of fuel, and the extent and efficiency of heating surface.

Instead of estimating by the heating surface it is, however, more convenient to take the maximum quantity of water that can be evaporated per lb. of fuel in any given boiler, which we may take at 10 lbs., whence we have—

$$S = \frac{g \times c \times 10}{3600} = \frac{g\,c}{360}$$

where S = lbs. of steam generated in one second,
g = area of fire grate in square feet,
c = rate of combustion in lbs. per square foot of grate per hour.

The velocity at which dry steam at more than 11 lbs. above atmospheric pressure escapes into the atmosphere, according to Mr. McFarlane Gray, is approximately represented as follows :—

$$W = \frac{P}{70}$$

where W = weight of steam in lbs. discharged per square inch of opening per second, and P = pressure in lbs. per square inch above zero.

In order that the steam may be discharged as rapidly as it is formed, the area of the safety valve aperture, or A, must be equal to $\frac{S}{W}$ or

$$A = \frac{g\,c}{5 \cdot 14\ P}$$

The velocity of discharge will, however, be governed, to some extent, by the dryness of the steam, and by the arrangement of the valve and its adjuncts. If the aperture be not sufficient to discharge the steam as quickly as it is raised, the *pressure* will increase, but not indefinitely. By the elevation of temperature and pressure the density of the steam and

the rate of efflux will be increased, and also at the same time the lift of the valve, whilst the load (except with springs) and rate at which the steam is generated remain constant, so that any increase of pressure due to insufficient size of valve soon reaches its limit.

It might seem reasonable to suppose that when the pressure lifts the valve from its seat it would continue to do so until the aperture of efflux is equal to the area of the valve, that is, until the valve rises to a height equal to $\frac{1}{4}$ its diameter, in the case of a flat disc valve.

It is, however, found that safety valves seldom rise more than about $\frac{1}{10}$ of an inch from their seats, unless the pressure at which they commence to blow off be very considerably exceeded; the diameter of the valve should therefore be calculated for a lift not exceeding $\frac{1}{10}$ of an inch. In order to obtain sufficient area it is better to increase the number than the size of the valves when the diameter is as much as five inches. The opening for the escape of steam with a conical valve is less than the lift; for a cone of 45°, the decrease is in the ratio of 7 : 10.

As the extent of heating surface may be considerably increased or diminished without materially affecting the evaporative power of the boiler, those rules for the area of safety valves based simply upon the area of heating surface are not of much value. Moreover, as the evaporative efficiency of the heating surface is not easily determined, the maximum efficiency of the heating surface should always be taken. The rules based upon the size of fire grate are not generally applicable, since the maximum rate of combustion, which must be assumed in these rules, varies in different kinds of boilers.

The valves in common use may be divided into two classes, according to the form of the joint made by the lid with its seat, viz., disc valves, having a flat-faced joint, and mitre or conical valves, with which may be also included spherical valves.

Flat disc valves are guided either by inside wings, central spindle, or outside pins. In their favour it is urged that they are much less liable to stick fast than conical valves, and when this is the circumstance that determines their selection in any case, the outside pin guide arrangement should, in consistency, also be adopted. On the other hand, an objection to this class of valve is the difficulty of keeping a tight joint at high pressures for a reasonable length of time. At 120 lbs. pressure it

is almost impossible to make the joint tight at all with a flat face $\frac{1}{8}$ inch or more in width. Another objection is the tardy escape of steam past the wide face, the direction being at right angles to its flow before reaching the valve, which leads to a considerable rise in pressure compared with that at which the valve lifts.

In favour of the mitre valve is the greater facility in keeping the joint steam tight when the bearing surface is not made too wide. A mitre $\frac{1}{16}$ inch in width is quite sufficient, and is found to answer far better for valves, at least up to four inches diameter, than bearings $\frac{1}{8}$ or $\frac{3}{16}$ inch, which are more common. The usual and best angle for the cone is 45°. The liability to stick fast increases with the acuteness of the angle, and it should, therefore, not be less than the above. It is sometimes urged against the efficiency of the mitre that it requires a greater lift of valve for a given opening than the flat face. Experience shows, however, that even as usually made, the mitre valve does not allow such a great elevation above the initial blowing-off pressure in the boiler as the other, the diameter of valve, rapidity of evaporation, and the pressure being equal in both cases.

At first sight it might be supposed that the exposure of an increased area of valve lid to the reaction of the steam pressure as it becomes lifted from its seat, especially in the case of a disc valve with wide bearing, would cause the valve to be still further lifted, and so favour the escape of steam. This, however, does not take place, and can be accounted for by the fact of the steam under the facing being in a state of motion, at right angles, in the case of a flat face, to the resistance, and not a vertical dead pressure, as it was before the valve lifted. Any increase of exposed seating area does not appear to have any influence in facilitating the efflux of steam by causing a greater lift; but on the contrary, the increased area diminishes the amount of escape from a disc valve to such an extent as to lead to a considerable rise, in some cases as much as from 12 to 20 lbs. above the initial blowing-off pressure of 60 lbs. or 70 lbs. The excess of area on the top of the valve, above that which is exposed to the steam pressure when the valve is on its seat, has to bear the additional unbalanced pressure of the atmosphere when once the valve is lifted. No doubt this has some influence in resisting the rise of the valve, especially with low pressures and wide faces. In connection with this flat-faced valve, it may *be mentioned* that the curious effect has been observed of the

valve lid being rather drawn to the seat than repelled, and maintained at a certain distance, which diminishes as the initial blowing-off pressure is increased. It is by many supposed that a valve once lifted will not close again until the pressure becomes reduced in proportion to the increased area exposed to the steam when the valve-lid is off its seat. That this is the case to some slight extent there can be no doubt, but not to such a degree as is generally supposed. The quantity of steam escaping after the pressure has subsided to the initial blowing-off pressure is usually only very small, and is much less with a mitre face or sharp edge than a wide flat face, which does not appear to cut off the current of steam so readily.

The valve lids are at present guided chiefly by inside wings or feathers, or by a central spindle. The former is decidedly the better plan, as the spindle is liable to get bent or stick fast by corrosion or dirt, which sooner or later insinuates itself. The wings are often made too good a fit, and stick fast when the valve becomes hot, especially when the casing is of cast iron, and the valve-lid is of brass. The method of guiding by outside pins is now rarely employed. Spherical valves require no guiding on their seat, and are in consequence less liable to stick fast, a most important advantage in a safety valve.

Safety valves are weighted either indirectly by levers, or directly by weights or springs. When the valve-lid is pressed down by a projection on the under side of a straight lever, an awkward lateral thrust is thrown upon the valve, in consequence of the centre of rotation being above the point where the thrust takes place. By bending down the fulcrum end of the lever sufficiently, this lateral thrust can be avoided. When, however, the weight is transferred to the valve by means of a pin loose under the lever, or secured by a double eye and bolt, the angular thrust is practically obviated. Instead of the pin bearing on the top of the valve, it is better made to act below the face or joint, whereby the angularity of its action is diminished, and the weight acts by pulling rather than thrusting, which produces a steadier action on the valve.

Another point in connection with the position of the fulcrum is that when the load is transmitted to the pin at a point below the centre of rotation of the lever, a rise of the valve reduces the leverage with which the load acts. This can be practically avoided by keeping the point at which the lever presses on the pin in the same horizontal line with the axis of rotation. Theoretically speaking, a feature common to nearly all straight

lever arrangements is that the leverage is reduced by the end of the lever moving in an arc when the valve rises. The reduction is, however, so slight in most cases as not to be worth considering.

A serious drawback in lever safety valves as usually constructed, is the liability of the pins or bolts at the fulcrum end to become fast by rusting, or from getting clogged with grease and dirt. The liability to corrode may be reduced by making the pins, double-eyes, or lever ends of gun metal. But in all cases it is better to do away with the centre pins altogether, and make the lever to turn on a knife-edge case-hardened, by which the friction is reduced to a minimum.

Lever safety valves, as usually constructed, are easily tampered with, and readily prevented from operating efficiently, if not altogether. It too frequently happens that the lever is made much longer than necessary for the blowing-off pressure with the weight provided. This allows the attendant, or any one actuated by mischief or malice, to increase the pressure in the boiler sometimes to as much as 100 per cent. above the safe working pressure. In order to prevent such an occurrence the lever should always be cut to the length suitable for the maximum pressure the boiler is intended to be worked at, or the range of the weight should be limited by means of a pin permanently fixed in the lever. Sometimes the weight is secured to its position by a padlock, which can be removed only by the owner, or other responsible person. On the opposite side of the valve casing to the fulcrum, there is usually a guide for the lever to work in, which, instead of being a simple fork, is made with the top bridged over. This bridge is intended to prevent the lever rising sufficiently high to allow the valve to be blown away in the event of the weight dropping off. Such an arrangement should, however, never be adopted, as it offers an opportunity of wedging down the lever and valve hard and fast, too often taken advantage of by reckless and careless attendants, when the valve is not steam tight for want of regrinding, or when the free escape of steam becomes troublesome. The commonest plan of overloading is to add to the regular weight, bricks, pieces of metal, or any other heavy article at hand by which the safety of the boiler may be endangered. In order that any overloading may be readily detected, only one weight should be allowed on the lever, and this should be on the end. To facilitate the operation of regrinding the safety valve, the lid should always be provided with a square or canted piece cast on, or other handy means for turning it round.

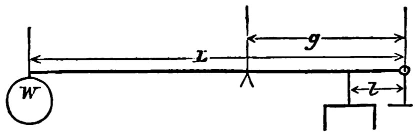
Where the boiler is closely housed in, and inconvenience is likely to arise from the steam escaping from the valve, it is usually led away by a waste pipe communicating with the casing round the valve. These box or bonneted safety valves, as they are called, add another source of danger in the spindle between the lever and valve, which, being made to pass through a hole or stuffing box, is liable to corrode, or otherwise stick fast. There should always be a small pipe to draw off the water, which, sooner or later, accumulates in the waste pipe, and which, if allowed to remain, will not only cause trouble by preventing the free escape of the steam, but becomes so much additional dead weight on the valve. In frosty weather this accumulated water is liable to freeze and choke up the escape pipe when the boiler is at rest, so as to render completely useless the means provided for relieving the pressure in the boiler. When a hole is provided in the bottom of the waste pipe, without other means for conducting the water away from the boiler, the plates near the safety valve often suffer seriously from corrosion. When it is required to keep the boiler house free from steam, the best plan is to carry the pipes or branches right through the roof, and fix the safety valves outside the building, care being taken that they are in a conspicuous and accessible position. The valves in this case should only be of external dead-weight construction.

In order to ascertain the weight necessary to apply at the end of the lever to balance a given pressure on the valve, there must be taken into account the load on the valve, due to the weight of the lever, as well as the weight of the valve itself and connections, which forms an increasing proportion to the total load, as the steam pressure is reduced, and the amount of leverage is diminished. The leverage with which the weight of the lever acts is measured by the distance of its centre of gravity from the fulcrum. The centre of gravity is easily found by balancing the lever on a knife edge, and the weights of the valve and lever can be ascertained by actual weighing.

The resistance due to the weight of the valve and lever is, however, best ascertained by lifting the lever on its place, having the valve temporarily attached, with a suitable spring balance applied exactly over the valve centre. But as this is done with the boiler at rest, it does not take into account the extra amount of friction thrown on the fulcrum pin by the pressure, and on the valve guides by the indirect thrust of the load when at work.

The required weight at the end of the lever is found by the following formula :—

Fig. 20.



$$W = \left\{ (P \times A) - \left(V + \frac{w \times g}{l}\right) \right\} \frac{l}{L} \qquad (1)$$

Where W = weight at end of lever,
L = distance between weight and fulcrum,
w = weight of lever,
g = distance of centre of gravity of lever from fulcrum,
P = pressure in lbs. per square inch above atmosphere,
V = weight of valve,
A = area of valve,
l = distance between valve centre and fulcrum.

When the load is given and it is required to find what steam pressure is balanced on the valve, we have

$$P = \left\{ \frac{(w \times g) + (L \times W)}{l} + V \right\} \div A. \qquad (2)$$

When the load and pressure are given, we have for the length of lever

$$L = \left\{ (P \times A) - \left(V + \frac{w \times g}{l}\right) \right\} \frac{l}{W.} \qquad (3)$$

The lever is sometimes prolonged beyond the fulcrum, and provided with an adjustable weight, which is set to balance the weight of the lever and connections. With this arrangement it is advisable to counterbalance the weight of the valve as well. The formulæ for finding the weight at the end of the lever, &c., are then simplified, and stand thus :—

$$W = \frac{P A l}{L} \qquad (4)$$

$$P = \frac{W L}{A l} \quad (5)$$

$$L = \frac{P A l}{W} \quad (6)$$

When the lever is pressed down by a spring balance at its extremity, a rise of the valve produces a considerable increase of pressure by the increase of extension or compression of the spring. It is customary to arrange the proportions of the lever so that 1 lb. per square inch on the valve is equal to 1 lb. pressure of the spring balance. With this arrangement the lift of the extremity of the lever is measured by the rise of valve multiplied into its area in square inches. This lift of the lever end in inches multiplied by the number of lbs. to the inch in the graduation of the balance, will give the additional load in lbs. per square inch placed on the valve by the mere act of rising. It is obvious that this additional resistance involves a corresponding increased pressure of the steam to obtain its discharge through the opening of the valve, over and above that which is always required to compensate for the loss of lifting pressure under the valve due to the motion of the steam at this part, and to overcome the resistance offered by the atmosphere. For example, if we take a four-inch valve, and suppose it to rise $\frac{1}{20}$ inch, this will give a rise at the end of the lever equal to $0{\cdot}05 \times 12{\cdot}56 = {\cdot}628$ inch. If the graduation of the spring-balance be 25 lbs. per inch, this will give ${\cdot}628 \times 25 = 15{\cdot}71$ lbs. per square inch, additional resistance to be overcome by the steam in order to get a lift of $\frac{1}{20}$ inch for the escape of steam.

Since the load pressing the valve down increases as the square of the diameter, whilst the area of the aperture increases only directly as the diameter of the valve, it is obvious that by increasing the diameter the increase of pressure necessary to obtain a given area of opening increases more rapidly than the opening for efflux, or that a large valve will involve a greater excess above the initial blowing-off pressure to obtain a given area of discharge than a small valve, the spring balance in both cases having the same rate of graduation. The increase of pressure from the extension or compression of the spring can doubtless be reduced to any extent by increasing its length; but in practice the length of spring is limited by circumstances of convenience. This additional resistance also occurs with a

spring acting directly upon the valve, the decrease in motion being balanced by a corresponding increase of resistance in the spring. Arrangements to compensate for the increase of resistance due to the rising of the valve, by reducing the leverage by means of a bent lever, have been successfully adopted.

In graduating the spring balances for locomotive and other valves, the proper weight can be found by formula (1), or allowance can be made for the weight of valve, lever, and connections. When the lever is proportioned so that 1 lb. at its extremity balances 1 lb. per square inch pressure, on the valve, or when $L = A\,l$,

$$W = P - \frac{1}{a}\left(V + \frac{w \times g}{l}\right) \qquad (7)$$

This shows that in graduating the balance we have only to make the scale lighter by the amount of load due to the weight of lever, valve, &c., when this has been ascertained. For example, if the constant load is found to be 7·5 lbs., the extension of the spring balance produced by 12·5 lbs. weight must be marked 20 lbs.; that produced by 22·5 lb. weight, 30 lbs., and and so on.

In graduating spring balances it is perhaps the rule rather than the exception to disregard the load due to the lever and valve. It is alleged in support of this practice that the extra area exposed to the pressure of the steam when the valve rises from its seat fully compensates for any excess of load not marked on the scale. For instance, with a 4-inch valve, having a $\frac{1}{16}$-inch bearing there will be an extra area amounting to ·4 square inches; this, multiplied by 60 lbs., would give 24 lbs., which might balance the load of lever, valve, &c., with a stationary boiler, but in the case of a locomotive working at 120 lbs. pressure, we should have an increase of pressure, on this assumption, equal to 48 lbs., which is decidedly too much. In fact, to carry out this argument we should have to proportion the bearing of the seat to suit various conditions of pressure, size of valve, &c. However, the increased exposed area of valve on lifting, as we have already noticed, has no material effect in facilitating the escape of steam.

Some makers profess to specially graduate their spring balances at the testing of the boiler with water, when the various *degrees of pressure* at which the valve lifts are noted from a

reliable gauge, and the spring balance scale is marked off accordingly. This method has certainly the advantage of taking into account the increase of load due to friction at both ends of the lever, and on the valve, if there should be any lateral pressure. But it is difficult to reconcile the alleged success of this method with the well-known fact that an ordinary valve will let water escape more readily than steam at the same indicated pressure. This method of graduating spring balances would be far better carried out with steam than with water.

Formula (2) gives, approximately enough, the pressure at which the valve will rise, when the arrangement, workmanship, and condition are not decidedly bad ; but the amount to which the steam pressure will rise above that at which it commences to escape will depend upon the degree of pressure itself, as well as upon the character of the valve and speed of evaporation.

Directly loaded or dead-weight safety valves, as they are called, are loaded either internally or externally. The latter mode is much to be preferred, as any attempt at overloading or tampering can be more readily detected, and the valve cannot be jambed down intentionally by fixing a strut between the weight and the boiler crown. The great load hanging on the spindle of an internal dead-weight valve has been known to drop off, or to break the spindle when it has been weakened by concealed corrosion. When this happens, the valve is blown away, and the discharge of steam and hot water are likely to prove disastrous, unless the valve is enclosed in a strong casing. The large bulk of metal used for loading a large internal dead weight valve is extremely inconvenient inside a boiler. In order to prevent the suspending spindle from getting bent by any one pushing past inside the boiler, the load should always be made free to swing.

The valve most likely to be found proof against neglect and malice is that of the external pendulous dead-weight construction, known as the "Cowburn" valve. Being directly loaded, it requires very considerable over-weighting to cause a serious rise of pressure within the boiler ; and the application of any irregular weights can be readily detected. Having no cross-bars, there is a clear way for the steam to act on the valve, which being spherical requires no guides or feathers to stick fast. The issuing steam, by impinging on the cylindrical weight, assists in lifting the valve from its seat. From observing the action of a great number of valves of various descriptions, the writer has been led to conclude that the "Cowburn" valve is the

most sensitive and reliable, and at the same time relieves the pressure more quickly than any other valve commonly used.

For stationary boilers spring balances should never be used, nor should the ordinary lever valve, in consequence of the facility with which it can be rendered inoperative. All spring balances for locomotive and portable engines should be provided with a ferrule between the nut and the spring casing, to prevent the valve from being screwed down beyond the blowing-off pressure. Sometimes, however, the thread on the spindle is made just of sufficient length to meet this object. In all cases where spring balances are used it should be ascertained that the spring is not compressed together so that the lever cannot rise, when the nut is screwed down as far as it will go, and that there is still flexibility enough in the spring to allow the valve to rise easily.

As all valves are liable to stick fast by corrosion when allowed to stand unmoved for a length of time, they should be daily eased on their seats. For this purpose, and also in order to test their freedom of action, valves of the direct-weighted spring class, and internally-weighted valves of all descriptions, should be provided with a lever or other means to ease them by hand. The lever should be so arranged that it cannot be employed to assist in keeping down the valve. Many lock valves and others arranged so as to be inaccessible and safe against being tampered with become fast and useless, and are rather a source of danger than otherwise when their efficiency is relied upon.

No boiler should be allowed to work without at least two good safety valves, in case one should become inoperative.

Some of these observations are repeated, with additional remarks on safety valves, in the chapter on Explosions.

Besides the safety valves above described for preventing any dangerous excess of pressure in the boiler by allowing the steam to escape into the atmosphere, there are numerous other expedients and arrangements in use for checking the rise of pressure beyond a certain point. There is, for instance, a plan for closing the damper by self-acting machinery on a certain degree of pressure being attained. By another expedient, hot water is discharged into the fire. But the majority of these apparatus are found to be troublesome and uncertain in their action. It may be remarked that discharging hot water from a highly-pressed boiler into the fire is liable to prove dangerous by scalding, and scattering the burning fuel about the stoke-hole.

In old boilers of very weak construction it is advisable to

have a safety valve opening inwardly, to any excess of atmospheric pressure that may occur when a vacuum is formed inside the boiler—a circumstance of frequent occurrence, and which has caused the collapse of several large weak cylindrical boilers.

LOW-WATER SAFETY VALVES.

Low-water safety valves are used to discharge the steam and relieve the boiler from pressure before the water level falls to a dangerous degree, either from neglect in feeding, or from the water escaping out of the boiler.

The arrangements of this description which have proved most efficient after long trial are the two well-known valves introduced respectively by Hopkinson and Kay. Either of these forms a most important adjunct to the safety of internally fired tubular boilers, from the timely warning they give of lowness of water. They are, however, easily tampered with and rendered useless. Their machinery, being inside the boiler, can be examined only when the boiler is at rest.

There are also numerous other expedients used for low water indicators. The simplest being variously designed float and lever arrangements connected with a whistle on the boiler. The majority of these are liable to get out of order, and have been found untrustworthy.

FUSIBLE PLUGS.

Fusible plugs, in one or more of the numerous shapes in which they are made, are more frequently applied than any other means as a safeguard against the collapse of furnace crowns from overheating through shortness of water. These plugs usually consist of a piece of alloy of tin, lead, and bismuth inserted in various manners in the furnace crown. So long as the alloy is kept at a comparatively low temperature by the water on the one side, it is prevented from melting by the fire on the other. But on the water level descending so far as to leave the plug dry, it is expected to fuse and relieve the pressure in the boiler, and at the same time to extinguish the fire and save the furnace plates.

Notwithstanding the great favour in which they are held, as proved by their general adoption, there can be no doubt that their efficiency has been much overrated, since numerous cases occur every year of the furnace crowns being burnt from short-

ness of water without the fusible metal becoming melted. This is partially due to the accumulation of soot and dirt that usually takes place in the cavity over which the plug is inserted, and partially in consequence of the alteration which takes place in the nature of the alloy during long exposure to the heat of the furnace.

There are also numerous instances of the fusible metal melting out without liberating the steam pressure. This is chiefly caused by the accumulation of incrustation on the metal being sufficiently strong to withstand the pressure upon it and prevent its liberation. The simple plan of screwing or riveting a piece of lead or fusible metal into a hole in the furnace-crown plate should never be adopted, on account of the leakage that often takes place when the plug is slack, which leads to the corrosion, patching, and destruction of the plate. Moreover, the plug will probably not melt until the crown shall have actually become bare. For this reason alone, there should be a provision on the furnace plate for the insertion of the plug to keep the crown still covered with two or three inches of water after the plug itself has been left bare. This is usually done by riveting or screwing a seating of wrought iron or gun metal to the furnace crown, into which the plug of fusible metal is fitted in various ways. Care should be taken to make the mouth of this seating at least two or three inches in diameter for the easy removal of the soot and for the free action of the heat.

In order to take advantage of the heat of conduction the area of the fusible alloy in contact with the casing is increased by making the plug of an annular shape, the middle being filled in with brass or copper. The same object is attained by dividing the alloy into several small plugs let into a large cap fitted to the seating. This has the further advantage of increasing the number of pieces depended upon for safety. Where the area, however, is small, greater care is necessary in keeping the metal free from incrustation, a coating of hard scale less than $\frac{1}{16}$ inch thick over a $\frac{1}{2}$-inch-hole being sufficient to withstand a pressure of 70 lbs. or 80lbs., should the alloy be melted out. This is equivalent to saying that less than a month's work with many boilers will render such a small plug useless. In making a selection of the description of plug the nature of the feed water should be taken into consideration. With feed water containing much carbonate of lime or magnesia in solution, especially where grease is present, many of the fusible plugs in use are found to be too sensitive and cause much trouble by melting, even when

there is still abundance of water over the furnace-crown. In such cases the failure of the fusible metal serves as an indication of danger from the liability of the furnace plates to overheat.

To guard against the risk arising out of the tendency to change in the nature of the alloy, it is advisable to renew the fusible metal every three or four months, and only those descriptions of plugs which admit of this being readily and efficiently done should be chosen.

It must not be supposed that the steam in an ordinary large-sized boiler can always be liberated with sufficient rapidity through a small hole, say ½-inch or ⅝-inch diameter, to prevent over pressure in the event of the furnace-crown becoming bare, and such a discharge of dry steam will often have little or no effect in retarding the combustion. On the contrary, if we may believe the testimony of many firemen and engineers, on the melting of the plug, the discharge of steam over a bright fire greatly increases the heat of combustion, the appearance of the furnace being changed from a red to a white heat. That this, under certain favourable conditions, would take place there can be little doubt, and it is probably one reason why fusible plugs have been found ineffective in preventing furnace tube collapse. When, however, the discharge of water or wet steam over the fire is large, combustion will be retarded, the pressure relieved, and warning of danger given.

PRESSURE GAUGES.

Besides having an efficient self-acting apparatus for preventing the accumulation of an undue pressure of steam, it is highly desirable as a check on the safety-valve and for obvious reasons, if not absolutely necessary for safety, that the boiler should be provided with a trustworthy pressure gauge for indicating the steam pressure at any moment.

The steam-pressure gauges almost universally employed are of two kinds, viz.: 1, the mercurial guage; and 2, the dial gauge. Of the first there are various descriptions, the simplest consisting of a long glass U tube containing mercury, open at one end to the atmosphere, and at the other end in connection with the steam in the boiler. The pressure of steam is balanced by the column of mercury, the various heights of the column corresponding to the steam pressure, being read off on a plainly marked scale alongside the tube. When the steam pressure exceeds that due to the height of the mercurial column,

measured from the top of the tube where it is open to the air, the mercury is forced out and allows the steam or water to escape. The area of the glass tube is in most cases, however, too small to liberate the pressure with sufficient rapidity to admit of this apparatus being relied upon as a safety valve. Instead of a glass tube one of iron or brass is sometimes used. The height corresponding with the pressure is, in this case, indicated by a light rod connected with a float on the surface of the mercury.

When the legs of the tube are of equal diameter a fall of one inch on one side will cause a rise of one inch on the other, the difference in the level will therefore be two inches, which is nearly equal to one pound pressure, or, strictly speaking, is equal to ·98lb. pressure per square inch above the atmosphere, or, 1 lb. pressure = 1·02 inches rise in one leg. Hence $P = L \times \cdot 49 \ldots (1)$, where P = pressure in pounds per square inch above the atmosphere, and L = difference in level in inches. When the tube legs are of different diameters the pressure is readily deduced from the height in the open leg and the ratio of the diameters.

Let h = rise of the mercury in leg of tube open to atmosphere,
d = diameter of ditto,
D = diameter of tube in communication with boiler,

then the descent of the mercury in the tube in communication with the boiler will be $= \frac{h\,d^2}{D^2}$. and the difference in the levels will be

$$L = h\left(1 + \frac{d^2}{D^2}\right) \qquad (2)$$

and

$$P = h\left(1 + \frac{d^2}{D^2}\right) \times \cdot 49 \qquad (3)$$

If it be be desired to graduate the scale to indicate directly the excess of pressure in the boiler above the atmospheric pressure, the length of the divisions, calling them inches, can be found thus—

$$G = \frac{1}{1 + \frac{d^2}{D^2}}$$

By making D very much larger than d when it is required to *increase* the scale for marking small variations of pressure, and

the fraction $\frac{d^2}{D^2}$ becomes very small, it may be neglected, and the column of mercury in the open branch measures the excess of pressure. On the other hand, by making d greatly larger than D, which is often done for convenience with high pressures, the length of scale may be reduced at pleasure.

The above formula (2) will not, however, give the precise difference of level, especially in the last-mentioned arrangement, in consequence of the quantity of water that lodges on the mercury in the branch of the tube communicating with the boiler. In order to correct the error likely to arise from this source it is advisable to fill the boiler branch of the tube full of water, and take the point where the mercury now stands at 0, and make allowance for the difference.

As the specific gravity of mercury is 13·6, the difference of level when the two branches are of the same diameter will now stand $h \times 1{\cdot}92$ instead of $h \times 2$. Formula (2) may be written—

$$L = h \left(1 + 0{\cdot}92 \frac{d^2}{D^2}\right)$$

As long as the tube branch is kept full of water this last formula will give the correct difference in level.

In order to avoid the inconvenience of having a long tube, the plan is sometimes adopted of closing the end of one branch and leaving a column of air in, which resists by compression the steam pressure in the other branch. These gauges, however, in course of time become inaccurate from the oxidising of the mercury and the consequent reduction in the volume of air.

The inconvenience arising from the glass in contact with the mercury becoming dull, and the liability to fracture, besides other disadvantages, especially when steam of high pressure is used, have led to the rejection of mercurial pressure gauges in favour of metallic or dial gauges, as they are usually called, which, although less accurate and reliable, are better liked for their convenient shape, facility of fixing, and small cost.

The "Bourdon" dial gauge, in which the principle of action is the tendency of a curved tube closed at one end to become straight when subject to internal pressure, when well made is perhaps the best in general use. But since the patent right has lapsed many wretchedly constructed and untrustworthy articles are sold as Bourdon gauges.

In all metallic spring gauges the connecting pipe should have one or more bends in it close to the gauge filled with water, which serves to transmit the pressure, and keeps the spring at a nearly constant and low temperature. In consequence of the large surface of pipe exposed to the air the water in the pipe and tube is kept cool, but it has the disadvantage of being liable to freeze in winter when in exposed situations.

For convenience of removal or examination when the boiler is at work all pressure gauges or their connections should be provided with suitable stop cocks to shut off the communication with the boiler. Yet, in consequence of the risk of deranging or breaking the gauge by suddenly letting on or shutting off the pressure some engineers prefer attaching their gauges without stop cocks.

In a range of boilers each should be provided with a separate pressure gauge, which should never be placed on the steam pipe, or where there is a current of steam flowing past the point from which the pressure is taken. In such situations they cannot be expected to indicate the correct pressure. The best position is on the boiler, or as near as possible, where there is no rapid motion of the steam, and where they are immediately under the eye of the boiler attendant, but out of reach of rough usage.

WATER GAUGES.

The presence of some means of ascertaining with certainty the water level at any moment is, with many kinds of boilers, of even greater importance than an efficient pressure gauge.

If, on the one hand, the water is too low, there is a danger, especially in internally fired boilers, of overheating the furnace plates; and, on the other hand, if the water level is too high, there is a risk of priming and other inconveniences.

The apparatus usually employed for indicating the water level are gauge cocks, glass water gauges, and floats.

Gauge cocks or valves of various designs, too numerous to mention, are perhaps the oldest and most generally used means for this purpose. They are generally two in number, placed one at the highest and the other at the lowest position it is considered desirable to have the water level. When the surface of the water stands between the two cocks it is evident that steam will issue from the upper, and water from the lower, when the cocks are opened. To ensure greater accuracy in the indications of the water level the number of cocks may be increased.

In flat-ended boilers the cocks are usually placed on the front end. In order to avoid errors in indication which too often arise from the agitation of the water, the cocks are sometimes screwed into a hollow tube of brass or cast iron attached to the boiler, with its ends opening into the steam and water spaces sufficiently far removed from the surface to be out of reach of the violent agitation of the water. In egg-ended and other boilers encased in brickwork above the water level, the cocks are usually attached at or near the crown. The height of the water in such cases is found by carrying small internal pipes from the cocks to the levels between which the surface of the water is to be maintained.

For the purpose of obviating the inconvenience arising out of the necessity of turning the gauge cocks by hand, a great variety of glass water gauges have been introduced, by which the water level is rendered self-indicating. The oldest and simplest of these consists of a glass tube, the top and bottom of which communicate by means of suitable fittings with the steam and water spaces respectively. The level of the water within the glass is taken to be the same as that within the boiler, and is always before the eyes of the attendant. To facilitate renewing, cleaning, or repacking, the glass gauge should always be provided with cocks for shutting off the communication with the boiler, and also a third cock for emptying the glass when it is required to drain off the water and to ascertain if the apparatus is working properly. This drain cock should always be provided with a waste pipe of ample size, and free from sharp bends, for carrying away the waste water from the boiler plates. The neglect of this provision often results in severe corrosion of the front end-plate of furnace-tube and locomotive boilers. There should always be provisions for cleaning out the steam and water passages of the gauge when the boiler is at work, in the event of their choking up with dirt or incrustation. The cleaning can be safely effected by using a suitable piece of bent wire. The absence of these provisions is a defect of many of the patented gauges in use. A common defect met with in most kinds of glass water gauges is the small diameter of the steam and water passages. These are seldom more than $\frac{1}{4}$ inch, whereas they should seldom be less than $\frac{1}{2}$ inch diameter. In the ordinary gauge the cocks are made either as plug taps or as packed gland taps, the latter being used for the purpose of concealing, but not preventing, the leakage that takes place when the taps are allowed to get out of order. It is the custom to

make the drain cock smaller than the others, whereas it should have the largest bearing surface, being used probably thirty times a day, whilst the others are not used more than twice or thrice, and frequently not so often. The effect of the present fashion of making these taps too small is the dirty condition too many boiler fronts are found in, especially when brackish and other hard waters are used. These taps often wear unevenly by being turned one quarter round and back again every time they are used. Taps always wear better when they are turned completely round. In order to enable this to be done, and to facilitate their regrinding, it is best to make the handle as a loose spindle, with a stop at each end, and working freely in an eye on the end of the plug or key as it is called. The handles are often made so weak as to be wrenched off without much exertion in attempting to turn the cocks. For comfort in grasping, the handles may be covered with leather. The method of fitting the handle on to a square on the end of the key has frequently led to the unsuspected emptying of the boiler down to the level of the water passage, from carelessly putting the handle on at the wrong angle. Such an occurrence as the escape of the water through the gauge, in consequence of the breakage of the glass overnight, when the fires are banked up, can be prevented by shutting off the communication between the water passage and the boilers. In ordinary sized furnace tube boilers the lowest visible point of the glass should never be less than 5 inches or 6 inches above the highest point of the internal flues. In some cases it is desirable to increase this distance. In consequence of the small steam space in locomotive boilers this distance is seldom more than three inches, but the greater care with which the water gauge is watched on this class of boiler renders a less margin of safety admissible.

In using dirty water, or when a large quantity of soda is introduced into the boiler, the level of the water in the gauge is rendered unsteady and unreliable in consequence of the water boiling over through the steam passage. This annoyance is easily obviated by carrying a small pipe well up into the steam space, out of reach of disturbance by the ebullition. Glass water gauges as usually constructed are not suitable for externally fired boilers with a mass of brickwork in front or with a wheel draught, unless the feed water is very free from impurities, as the long horizontal steam and water spaces necessitated are liable to become rapidly choked up and to render the gauge a source of trouble. To overcome the difficulty arising

out of the long passages, some engineers have adopted the plan of attaching a cylinder to the front end of externally fired plain cylindrical boilers. This cylinder projects through the brickwork and to its flat end the water gauge is conveniently fixed.

It is always advisable to have two water gauges to a boiler, the one being a check upon the other, and acting as a reserve in case of a glass breaking, or any other accident happening to a single gauge. As to the best position for the gauge, it should be at the furnace end of the boiler, where it is under the eye of the attendant. It must, however, be admitted that it is here most liable to the disturbing influences that take place inside the boiler, which render its indications inaccurate and misleading unless proper precautions are taken to obviate these objections.

It has been proposed to insert a piece of glass in the boiler front or other accessible position, to enable the water level inside the boiler to be directly seen and read off against an internal scale introduced for the purpose. It would, however, be necessary, at the same time, to illuminate the interior of the boiler by means of a lamp shining through another opening. Such an arrangement could only be satisfactorily applied to waters free from such impurities as would be likely to besmear the scale and inside the glass.

The water-level indicator most commonly used for externally fired boilers is the float. The common arrangement of this apparatus with its external counterbalance and pulley is too well known to require description. Besides this, there are numerous other arrangements, some of which have the counterbalance inside the boiler, and indicate the water level by means of an external index-lever. To the common float is sometimes added a whistle, arranged to blow and give warning by self-acting gear when the water level descends to a certain point beyond which it is considered not safe to sink. The well-known defect attending the use of the common float is the liability of the wire passing through the stuffing box to stick fast from being too tightly packed, or from being bent when the boiler is being cleaned out. This wire should never be made of iron, as it rapidly corrodes, destroys the packing and allows the steam to pass, and then an attempt at tight packing is sure to follow. Many engineers prefer having the wire not more than $\frac{1}{8}$ inch thick, as it is more easily packed without the aid of a stuffing box and gland, and does not so easily become permanently bent as a $\frac{1}{4}''$ or $\frac{5}{16}''$ *inch wire*, so commonly used.

In consequence of the difficulty above mentioned in connection with the use of glass water gauges, the float is to be preferred for plain externally fired boilers, but there should always be two to each boiler. When carefully constructed and not neglected, the float is a reliable water-level indicator, but it requires a great deal of attention to keep it in order. It may be placed in any part of the boiler where it is not affected by the broken water produced by violent ebullition, and where it is least likely to interfere with the cleaning and examination of the boiler or circulation of the water.

BLOW-OUT APPARATUS.

The bottom blow-out apparatus is used not only for emptying the boiler, but also for getting rid of some of the dirt and sediment in the boiler by discharging a limited quantity of water at intervals with the steam up. It is therefore important that the apparatus should work freely and be conveniently situated. Being placed at the bottom where it can completely drain the boiler, it is of still greater importance that its tightness can be depended upon when the apparatus is shut, as a small amount of leakage continued for a length of time might involve the overheating of the furnace plates and the destruction of the boiler.

For freedom in working, valves, if properly made, are superior to taps even of the best construction, but, as a rule, they are not so trustworthy, and therefore should not be employed. Valves of nearly every description, whether conical, disc, or sluice, have all the same fatal defect, viz.,—liability to mislead when apparently closed. A small chip or piece of incrustation getting on the seat of a conical valve will prevent its closing tightly when to all outward appearance it may seem quite shut. The accumulation of deposit at the bottom of the casing under a sluice valve may soon render its closing securely impossible, and although screwed down hard and fast the valve may still be slightly open. By using care, and counting the number of turns given to the spindle in opening and shutting, and marking the exact point the handle should return to when closed, it may be ascertained whether the valve be closed or not. But it is just the exercise of this care that cannot be reckoned upon, and the absence of which renders the employment of valves in critical situations so dangerous.

The duty of filling the boiler and lighting the fire after

cleaning, often devolves upon some other than the regular attendant, who, after screwing down the valve concludes all is right and tight, and seeing plenty of water in the gauge leaves the boiler to itself for an hour or two. The valve after all may have been prevented from closing properly by some obstruction on the seat. The result follows that the water escapes unperceived through the valve, the furnace plates become drained and overheated, and if there be any steam in the boiler the flues collapse or the shell is rent. Such cases have frequently happened. From the quiet manner in which the water escapes when there is no pressure in the boiler, its loss is then more likely to happen unperceived than when the boiler is at work, as the hot water in escaping under pressure usually makes some audible or visible sign.

The valve that is least likely to cause deception in not closing tightly is a kind of butterfly valve with triangular openings, where the flat disc forming the valve-lid revolves on the valve face which it is prevented from leaving by a guard, which, however, requires adjusting as the faces wear. These valves work very freely and are perhaps as reliable as some gland taps.

With a tap in good order there can be no deception as to whether it is closed or not when turned off, and so far as trustworthiness is concerned, they are better adapted for blow-out apparatus when properly constructed, than any kind of valve.

The principal drawback to taps of all kinds is the manner in which they stick fast from becoming corroded or incrusted together when not used frequently, or from the quicker expansion of the plug compared with the shell on being turned on. The remedy for the first evil or defect is obvious, and the best means for remedying the second is to work the plug gently backwards and forwards until the shell is heated through, when the tap may be fully opened and shut again immediately, with comparative ease. This is better and safer than suddenly turning the tap full on with the aid of a dangerously long lever, and waiting until the shell is heated sufficiently to turn it off again. The tendency to stick fast is greatly aggravated when the casing is made of cast iron and the plug of brass, a practice which should be altogether condemned, since it has been productive of serious inconvenience and even disaster. It is seldom that the taps about boilers are found sufficiently hard to wear well, being made of red brass instead of gun metal, for the sake of being more easily fitted up and refitted, and also, of course, to save *first cost*. When two metals of the same

nature are pressed together with considerable force and allowed to remain in contact for some time, they are apt to cohere or "seize." This tendency is increased by making the metals soft, and is one cause of the sticking fast of taps. It may, in some measure, be obviated by making the plug and shell of slightly different alloys, the former being the softer as it is more easily replaced when worn out. As a rule, blow-out taps are made too short or have too little bearing surface to last long without regrinding, and the universal practice of turning the taps one quarter round for opening, and then back again for closing, causes uneven wear and leakage. Every time the tap is opened, it should be shut by giving it another quarter revolution in the same direction; by this means the tap wears more evenly and lasts longer without regrinding.

There is a great difference of opinion respecting the best taper for large taps, some advocate 1 in 4, others 1 in 6. The former sometimes cannot be kept tight, and the latter are liable to stick fast if screwed down sufficiently to prevent leakage. The circumstances to be considered in determining the taper in any case, are the steam pressure used, the hardness of the metal, frequency of lubrication, and nature of the lubricant and water employed. For pressures of 20 or 30 lbs. a taper of 1 in 4 is found to work well, but for pressures of 90 or 100 lbs. a taper of 1 in 6 is necessary to insure tightness.

In the common plug tap the nut securing the plug is liable to work loose and drop off without being observed, as the tap is usually placed in a position difficult of access and examination. Serious cases of scalding have been occasioned by the blowing out of the plug from this defect. For facility of observation the tap is best arranged horizontally, and the plug should be further secured by a guard to prevent it from being blown out in case the nut should drop off from the thread stripping, or other cause. Such an occurrence could, however, be prevented by simply putting in a pin through the bolt behind the nut.

In order to avoid the risk of the plug blowing out, as well as to conceal, but not cure, the leakage which takes place when the tap requires regrinding, packed gland taps with a closed bottom are used by many of the best makers, and to obviate the stiffness produced by the friction of the packing against a large surface, compound gland taps are sometimes used, but with questionable success. It is still an open question whether the best description of gland tap is better than the old-fashioned

plug tap provided with a guard for the plug. Many cases have occurred of the water leaking to a dangerous extent past the plug in a gland tap without being detected in time, an event much less likely to occur with the simpler description of tap. In using gland taps with brackish or other very hard water, the plug is sometimes prevented from being screwed down to its seat by an accumulation of incrustation which has taken place between the casing and the bottom of the plug. This is likely to happen when the gland nuts are eased back to allow the plug to rise and ease itself for turning readily, a practice often necessitated by the faulty construction or defective condition of the tap. Such an occurrence could not possibly happen with an ordinary open-bottom tap. Inverted plug taps with hollow plugs designed to be kept tight against their casing by the internal pressure, and those arranged to discharge through the open plug bottom, cannot be recommended. However well such taps, when of small size, may be found to answer in certain situations, they are not satisfactory when of large size, and are not adapted for using in connection with waste pipes.

The practice of making the blow-out apparatus of furnace tube boilers without waste pipes cannot be too strongly condemned. Too frequently the hot water is discharged into a drain only a few inches below the floor line, from which it rebounds, and renders the duty of blowing off a very dangerous one; at the same time, it is advisable that the end of the waste pipe should not be placed altogether out of sight, so that any leakage which may take place may be detected.

As the safety of a boiler depends so much upon the condition of the blow-out apparatus, the task of blowing out should be regularly performed at least once a day by the engineer in charge, and should not be left to the fireman.

In tubular boilers, for facility of access, the blow-out tap should be placed clear of the front end, and connected by a short elbow pipe with the mouthpiece or branch riveted to the boiler bottom. This pipe as well as the cock should be carefully protected from contact with moisture and ashes, which too often find their way beneath the floor plates and cause the rapid destruction of the pipe, if not properly protected or made of copper. Comparatively few externally fired boilers are provided with a blow-out apparatus. The common practice is to provide nothing further than an iron taper plug which fits into a hole in the boiler bottom over the fire, by which the boiler is emptied. The plug is usually knocked out, when required, by

the rudest means imaginable, and it frequently happens that the person, who is bold enough to do it before the water is cold, gets scalded if he is not quick in making his retreat. In some cases the plug is more sensibly attached to a spindle passing through a stuffing-box on the boiler crown, and provided with a screw and handle to raise it with. Means should always be provided with this arrangement to guard against the plug and spindle being blown out by the pressure, in case the screw is carelessly turned round too far and looses its hold in the nut.

With plain cylindrical boilers, the blow-out apparatus sometimes consists of a tap or valve, placed on the boiler crown and connected with an internal pipe reaching to within an inch of the boiler bottom. This pipe may be made to extend for some distance along the boiler to collect the sediment it is required to blow out. When the apparatus so arranged is used for emptying the boiler, it has the drawback of requiring the emptying to be effected with the steam up, a practice especially dangerous with externally fired boilers encased in much brickwork. The blow-out is otherwise arranged by carrying an external elbow pipe from the boiler bottom through the brickwork at the side, or back end of the boiler, terminating in a tap or valve. For the purpose of protecting the pipe from the impingement of the heated gases it is loosely encased in brickwork. With this arrangement it is necessary to blow out very frequently when the feed water is of a hard or muddy nature, to prevent the deposit filling the blow-out pipe and becoming baked hard.

Remarks on surface blow-out apparatus will be found in the chapter on Incrustation.

MANHOLE COVERS.

There is perhaps no better proof of the ignorance or recklessness that may be displayed by makers of reputation, than the number of boilers turned out by them with unguarded manholes. The too common practice of cutting a piece of plate about 15×12 inches out of a boiler shell without providing any strengthening piece to the edge of the hole, where the tension on the plate is concentrated and where it is liable to be further weakened by wasting, cannot be too severely censured, and has already led to numerous fatal explosions. The plate, *at the edge* of the hole, in such cases, has to bear, not only the *strain from* the steam pressure which holds the cover up to its

work, but also what is often much more trying, viz., the strains put upon it by screwing up the cover, often weak and defective in shape, to make a tight joint, by means of the bolts suspended from the bridge bars or cross piece usually employed. When the joint leaks from want of stiffness in the plate itself or in the cover, or from bad fitting, or from the presence of a piece of interposed scale or hard substance in the cement or india rubber, the cover is perseveringly screwed up, and it becomes merely a question of time, and power available for screwing up, for the plate to become buckled and fractured at the edge of the hole at right angles to the cross piece, which unfortunately is usually in the position most likely to prove fatal to the existence of the boiler. In boilers at work the edges of these unstrengthened manholes are sometimes found split in four or five places, any of which fractures are ready with a little overpressure in the boiler, or with a little additional wasting, to develop into the primary rent of an explosion. In rag-boilers these unguarded manholes are sometimes as large as 36″ × 24″.

The edge of the plate can be cheaply and adequately strengthened by riveting on a ring of wrought iron. These rings are, however, too often so paltry, and applied in such an ignorant manner, that their application tends rather to aggravate than lessen the evil they are supposed to obviate. The ring should be at least $\frac{5}{8}$″ thick and 4 inches wide, so that the rivet holes at 3 inches centres, and not 6 or 7 as is usual, may be kept well away from the edge of the hole. These internal covers made to fit the curvature of the shell are an unmechanical job at the best, and a tight joint can never be depended upon with them.

It is far better, in all cases, to have a flat face on which to make a good joint with the lid, which should be secured by strong studs or bolts and nuts. This can be contrived in various fashions, either as a cast-iron branch or mouth-piece, or where lightness is aimed at, of wrought iron, or as a simple stout ring when the size and construction of the boiler make it difficult to enter. The longer the neck of the mouth-piece the larger should be its diameter. If it be more convenient to have the cover internal as for the mud holes at the front end of double-furnace-tube boilers, it can still be made with a faced joint, and held up by means of a bridge bar and bolts and nuts.

MUD HOLES.

Mud holes should always be provided at the front end of *double-flued boilers*, as their absence necessitates lifting the dirt

from the boiler bottom up through the manhole, which increases the labour and greatly interferes with the effective cleaning of the boiler. Moreover, the want of ventilation through the boiler from the absence of a bottom opening keeps the interior for a long time damp, and increases the difficulty of examination. The work of cleaning out Cornish boilers, especially when there are strengthening hoops round the tube, is very difficult and tedious, and may be much facilitated by having a mud hole at the front end. This, however, requires a special provision, owing to the limited amount of space at the bottom of these boilers, between the tube and shell. This provision can be well enough arranged, without materially weakening the shell of the boiler, which is the objection usually urged against the adoption of this plan.

In boilers, where the construction does not admit of any one entering for the purpose of cleaning and examination, a number of mud holes and wash-out plugs should be provided where they are most likely to be required, as, for instance, in agricultural and locomotive boilers, at the firebox shell corners and ends above the foundation ring, and also at the front and sides, to command a range over the crown of the inside firebox. These holes at the sides could often with advantage and safety be made much larger than is usual, to enable a man to get his arm in to clear away the deposit which resists being displaced by a jet of water from the hose pipe. For clearing out the barrel of these boilers wash-out plugs should be screwed into the smokebox tube plate, where there is not room for mud hole doors.

Mud holes are sometimes made in the firebox bottom ring. These admit of a rod being pushed up among the stays, to remove the concretion lodging on them; but as they are troublesome to keep tight, they are seldom repeated in new boilers.

In many locomotive boilers, manholes are wisely fitted to the bottom of the barrel, which afford considerable facilities for examining and cleaning the plates and tubes in their vicinity. The manhole mouthpieces are often made of good depth, and serve as mud collectors, when a cock should also be provided in the cover for frequent blowing-off.

The practice of simply screwing a taper wash-out plug into firebox shell plates, which seldom exceed ½ inch in thickness, although convenient and cheap, cannot be recommended, as the scanty thread allowed becomes rapidly destroyed by the iron rods introduced for removing the concretions, and the edges of the plates round the holes become rapidly reduced by corrosion. Welding on bosses or riveting on pieces of plate, or flanged

bosses for increasing the number of threads, does not get over the disadvantage of having the threads inside the hole, and to obviate this it is better, in nearly all cases, to apply a mouth-piece of brass or wrought iron, having an outside thread and cap. For the small mud holes or hand holes at the firebox water spaces of agricultural and locomotive boilers, perhaps the most convenient form of cover is the common internal lid, held up to its seat by a bow and stud. The edge of the plate round these holes is, however, liable to waste by corrosion, when the joint is not tight. By riveting a $\frac{5}{8}$ or $\frac{1}{2}$ inch ring round these holes, a good joint can be ensured by securing an external cover by 3 or 4 studs, which can be easily arranged so as not to give trouble by being liable to get bent, or by interfering with the cleaning.

In vertical boilers of the small class there should be a hand hole opposite every water tube, as well as a few for the furnace crown and at the bottom of the water space.

STEAM DOMES AND STEAM CHAMBERS.

Notwithstanding the general opinion that the presence of a steam dome is essential for obtaining dry steam, and as a remedy for priming, it should be regarded as an useless and expensive appendage to a boiler, and as frequently applied, a source of real danger. The practice of cutting a dome hole 3 feet or even 3 feet 6 inches diameter in a 7 feet stationary boiler, or a 2 feet hole in a 4 feet locomotive boiler shell, without providing against the weakening of the plate involved anything further than the dome plate itself and its angle iron or flange, cannot but be regarded as barbarous. In many cases the size of the dome and its hole is limited by the width of the shell plate, the whole of which, except some 5 or 6 inches at each end for the lap and dome attachment, is cut away. Many instances may be met with in shells having the plates arranged in parallel courses, where the weakened plate is prevented from giving way solely by the support due to the adjoining plates overlapping it on the outside; were the dome on the outer instead of in the inner belting of plates, the weakened plate would inevitably yield to the pressure.

Where the steam user must have a dome, there is no necessity for cutting away the plate more than sufficiently to allow a man to pass through; and when the margin of safety is small, the edge of *the plate* round the hole should be adequately

strengthened by having a stout wrought iron ring riveted to it. Yet it must be admitted that the tendency to prime is increased as the area of the hole is diminished.

The supposed advantages of a dome are two in number, viz. : 1. By increasing the steam space, it is supposed to act as a useful reservoir of steam, to meet any sudden demand arising out of irregular loads on the engine. 2. It is supposed to act advantageously as an anti-primer, since the steam, being further removed from the water, is supposed to be less liable to be saturated, especially when the dome contains a perforated diaphragm for arresting the passage of the suspended particles of water.

Now, with regard to the first of these statements, it can be easily shown that an ordinary-sized dome adds comparatively little to the steam room of a boiler. If we take, for example, a Lancashire boiler 7 feet by 30 feet, the steam space will be about 240 cubic feet. With a dome 3 feet by 3 feet high, we would have about 21 cubic feet capacity, which is less than 9 per cent. of additional space, and this would be exhausted by a few strokes of the engine. But the reservoir of power in a boiler resides not so much in the steam as in the heated water. With a working pressure of 60 lbs, each cubic foot of steam in the boiler will produce only 4·65 cubic feet of steam at atmospheric pressure, but 1 cubic foot of water in the boiler will produce nearly 35 times that amount, for at 60 lbs. pressure the temperature of the water is 307·5°, or 95·5° above the boiling point at atmospheric pressure, and, as every degree of heat added to water already at 212° may be taken as competent to generate 1·7 cubic feet of steam, 95·5° will produce 162·35 cubic feet, or nearly 35 times as much as 1 cubic foot of steam at 60 lbs. pressure. Whence it may be concluded that in ordinary boilers the addition to the power by the reserve of steam in a dome is insignificant when compared with the power stored up in the water. With respect to the second alleged advantage, it appears to be taken for granted that the higher the point at which the steam is taken from the boiler and consequently more distant from the agitated surface of the water, the drier is it likely to be. Now, without considering the cooling effect on the steam by the circumference of a large dome exposed to the atmosphere, this would be a correct conclusion if the steam flowed slowly and quietly into the dome. But this is not the case with the engine at work, when the steam rushes into and through the dome with great velocity, and is liable to take

a quantity of water along with it, causing the steam in the dome to be actually wetter instead of drier than the steam in the rest of the upper portion of the boiler.

Priming is promoted, if not actually caused, by the reduction of pressure, and consequent increased ebullition of the water immediately below that point of the boiler whence the steam is drawn, which disposes the water in the form of spray, to be carried along with the ascending current of steam. Not only is the water thus carried into the steam pipe, but also any particles of earthy and other foreign matters that may happen to be at the broken surface of the water. In boilers fed with dirty water from canals and drains, the inside of the dome sometimes becomes plastered with mud and clay, several inches thick, whilst the rest of the steam space remains quite clean.

Priming is also probably due in some measure to the flow of steam over the surface to the point of efflux, carrying particles of water along with it by the induced current it produces.

The various anti-priming expedients usually employed, such as the insertion of perforated diaphragm plates in the dome, and baffle plates for beating back the ascending particles of water are seldom effective, unless the system is elaborately carried out. The simplest and at the same time the most effective way to prevent priming is to avoid, as far as possible, causing any violent local ebullition or rapid current in drawing off the steam, which may be done by employing an internal perforated pipe, with the ends closed and fixed near the top of the boiler, into which the steam can flow quietly. The longer this pipe is made the better. In ordinary stationary boilers, a pipe 6 or 8 feet in length, with perforations, having a total area considerably in excess of the area of the pipe, is found to be all that is required as an anti-priming apparatus. The larger the collective area of the perforations, as compared with the area of the pipe, the more quietly will the steam flow through them, and when once within the pipe and separated from the water, the velocity of the steam can have no effect in producing priming.

Sometimes the success of this pipe is frustrated by carelessly leaving a large open space between it and the pipe leading the steam away from the boiler, through which a rush of steam takes place, and the action that causes priming is induced. The tendency of the perforations to choke up when certain kinds of dirty water are used has been alleged, in a few rare instances, as the cause that has led to the abandonment of the

pipes. They are successfully used on some railways in locomotive boilers, having very limited steam spaces. When used in locomotives the perforations should not be carried too near the ends of the boiler, lest the water splashing back from the ends should gain admission to the pipe.

The tendency to prime may be increased by urging the fire, or by drawing the steam from a point over the furnace or where the ebullition is violent; by the presence of grease and other matters which impede the free escape of the steam from the water surface, or by the immoderate use of soda which causes the water to foam. New boilers and especially new locomotives prime most in consequence of the violent ebullition that takes place over the clean heating surface, and also, sometimes in consequence of the greasy and dirty state of the interior.

All the phenomena in connection with priming, have not yet been satisfactorily explained. Melted tallow or oil is sometimes injected into small vertical boilers to prevent priming. It is supposed to have the same effect on the disturbed surface of the water that oil has when poured on a rough sea, so well known. And yet it cannot be disputed that the presence of grease in combination with other impurities increases the tendency of many boilers to prime.

When domes are used, the opening at the dome bottom should be made as large as possible, in order to diminish the tendency to prime. But in order to maintain the strength of the shell, where a large hole is made in it, the plates round the dome bottom will require to be adequately strengthened by means of a stout ring riveted round the edge of the hole, or else by strong internal transverse stays suitably arranged fore and aft of the dome. Sometimes the dome itself is strengthened by shrinking on a strong wrought iron ring near the bottom.

It is sometimes asserted in favour of the use of domes for locomotives, that they form a convenient seat for the safety valves, but when these are blowing off violently, they greatly increase the disposition to prime.

FURNACE FITTINGS.

The furnace is usually comprised of mouthpiece with doors and bed-plate, fire bars, bridge, and ash pit, with or without doors and dampers. In addition to these, some arrangements of furnace have special provisions for smoke burning and pre-

vention, cleaning out flues and fires, removal of clinkers, ashes, &c.

In externally fired boilers, the furnace is necessarily made quite distinct from the boiler. The circumstances which determine the best height for the boiler above the fire bars will be considered in the chapter on Firing.

By increasing the distance between the fire and the boiler, the perfect combustion of the gases will be facilitated, and the temperature of the plates will be reduced. The entering cold air will also be more diffused and not so likely to be directed against the hot shell to cause sudden contraction.

The arrangement of the furnace mouthpiece will depend mainly upon the arrangement of the flues, as the brickwork at the front end requires supporting by an arch or other means, when there is a wheel draught or split draught, and only a plain wall in front of the boiler is required when a flash flue is used. With respect to the best position for the fire door, which should be hinged to open sideways, and be made double in number if the grate is very wide, it should be arranged with a view to prevent as much as possible the impingement of the entering cold air against the hot shell plates when the door is thrown open, and it should be sufficiently wide to enable the fireman to distribute the coals properly over the grate. It should be kept from 12 to 18 inches from the fire to prevent destruction by the high temperature of the furnace. The durability may be increased and the radiation of heat impeded, by fitting a baffle plate of wrought iron to the door with an air space of 2 or 3 inches between. A casing or lining of brickwork is sometimes used behind the door for this purpose. These doors are often made excessively high for small boilers, about 12" is generally sufficient unless the grate is very long.

The common practice of applying a large casting for a furnace mouthpiece to the front end of an internally fired boiler must be discountenanced. The castings are not only cumbersome, costly, and liable to fracture sooner or later, but they conceal the ring of rivets attaching the tubes to the end plate, which are best left exposed to view for the detection of leakages and fractures. The best plan is to make the mouthpiece simply of two wrought iron plates with an air space between. The outer plate, to which the door is attached, may be fitted to the tube hole in the boiler front end plate, and the joint covered with a brass moulding. This arrangement allows the rivet heads to be exposed to view, and imparts a neat appear-

ance to the furnace. The plan of building up the front end of the boiler with a mass of brickwork to prevent radiation should never be employed, since it is liable to harbour moisture in contact with the front end plate. Another great evil attending this plan is the concealment of any outward bulging that may occur in the event of the failure or original want of strength in the staying. Many a boiler has been saved from bursting by the timely warning given of weakness by the bulging of the end plate, and any plan which interferes with the detection of this should be employed with extreme caution. When it is desired to prevent loss of heat by radiation from the front end, a coating of good non-conducting composition may be applied in a suitable frame, which can be arranged to leave a space between the plates and the non-conducting material, to admit of easy removal, and so as not to cover any of the rivet heads, except those of the stays.

The doors should be provided with a sliding or revolving grid for admitting air above the fire, the baffle plate being perforated to aid its distribution. A host of inventions for making the opening and closing of the slide self-acting have been patented. As a rule, it may be said that these self-acting apparatus are allowed to fall into disuse after a short trial, as most of them soon get out of order and require a good deal of keeping up.

The dead plate, often perforated with advantage to admit air, can be secured to the furnace mouthpiece, and arranged to rest on the furnace sides, so as to dispense with brackets secured by bolts to the plates which are liable to leak, and in consequence should always be as few as possible.

The fire bars are usually made of cast iron. The numerous shapes in which bars are made have been adopted mainly with a view to increase their durability, according to the experience or theoretical notions of their designers. For easy handling, the bars should not much exceed three feet in length. In order to facilitate the access of air, the fall of the ashes and clinkers, and the cleaning of the fire from below, the bars should be made thinner at the bottom than at the top; but in order to maintain the same windage or space between the bars when they become worn, they should be made parallel for about $\frac{3}{4}$ of an inch at the top, and then tapered downwards. It may be questioned whether any description of fire bar has given better results in the long run than the ordinary short cast iron bar $\frac{3}{4}$-inch thick at top and $\frac{3}{8}$-inch at bottom and 3 inches deep in middle, where it is

provided with a distance piece of the same width as at the ends to prevent twisting. The rapid deterioration by twisting, bending, or fusion sometimes experienced, is due to overheating, which may be caused either by a single bar here and there being, from some cause or other, raised above the general level of the grate, or by the air space being too wide, either originally or by lateral bending of the bars, caused by want of sufficient room to expand or other defect, which allows the red hot fuel or clinkers to get between. So long as the cold air comes in contact with the whole depth, the bar will only waste away on its upper surface, and that but slowly, unless the fuel like anthracite, burns with a very intense local heat. The air space usually allowed and found to answer best with good semi-bituminous coal is $\frac{7}{16}$ or $\frac{1}{2}$-inch. This space may, however, be diminished with advantage when there is a good draught, abundant boiler power, and the coal is clean. In burning anthracitic coal which decrepitates and falls through the bars, or where the coal yields much clinker, which adheres to the bars and gets between them, the windage might be kept smaller if the nature of the coal in the one case did not demand a considerable air space to insure a good draught for its combustion, and in the other case to provide for its becoming partially choked up. With coal that cakes much, or yields a large quantity of ash, the air spaces may with advantage be made $\frac{5}{8}''$, or in some cases even more.

With a view to facilitate removal and replacing, and to obviate the inconvenience and loss arising out of the single bars becoming lifted from their seats, and at the same time to increase the lateral stiffness, the bars are often cast together in sets of two or more, with end and intermediate distance-pieces between them to prevent twisting, which provisions should indeed be made in all cases. There should always be a liberal allowance at both ends for the bars to expand freely. The play to be allowed may be taken as 1 in 24. The plan sometimes adopted of tapering off the end of the bars and resting them on an inclined seating for the purpose of facilitating expansion cannot be recommended, as it leads to a difficulty in keeping the level of the grate uniform, the bars becoming overheated in consequence.

It has been observed that after repeated heating and cooling cast iron becomes permanently elongated. According to M. Brix a fire bar after seventeen days heating preserved a permanent elongation of 2 per cent.; another bar of the same dimen-

sions, after longer usage, was permanently elongated 3 per cent.

It is a common practice to incline the grates downwards towards the back end. No doubt this arrangement facilitates the pushing back of the fuel, and is useful in burning coal which produces much flame, but it makes it more difficult to ascertain the distribution of the fire at the back end, especially in a long grate.

In order to prevent active combustion in contact with the furnace plates of tubular boilers, likely to be followed by a current of cold air impinging on the heated part, the side bars are sometimes judiciously arranged to bear against the plates. A similar arrangement might be with advantage adopted in small vertical boilers, where the furnace plates are sometimes burnt by the bottom of the water spaces becoming choked with an accumulation of deposit.

With respect to the relative durability of cast-iron and wrought-iron fire bars it may be remarked that the point of fusion of the latter is considerably higher than that of the former, but wrought-iron bars bend and twist much sooner than bars of cast iron. For locomotives and agricultural boilers, where the fire bars are subject to rough usage, wrought iron bars, being less easily broken, are generally preferable to those of cast iron.

When the coals used are of a caking nature and adhere to the bars, or cause trouble by the quantity of scoriæ they yield, various arrangements for giving the bars a rocking motion for breaking the fire and detaching the clinkers have been invented. Some of these have been used with advantage, but the trouble and expense of keeping them in repair appear to have operated against their coming into more general use.

With the view of increasing their durability, the bars are often made hollow to allow a current of cold air or water to pass through. The air and water by becoming heated also adds to the efficiency of the furnace. The advantage of these expedients is, however, questionable, in consequence of the extra first cost involved and the expense and trouble of keeping them in good order.

The bridge is a low vertical wall or partition at the back of the grate, and forms a back end to the furnace. It is usually made of fire brick or cast iron surmounted by fire brick. The bridge is sometimes hollow, perforated, or split to admit air behind the furnace for burning the gases. Sometimes, however, the bridge is a wrought-iron water space communicating with the inside of the boiler. When water bridges are used care

should be taken that the ends incline or curve upwards to facilitate the escape of the steam bubbles as they are formed on the inner surface.

The bridge acts usefully in bringing the flame in contact with the heating surface, and by retarding the escape of the gases into the flues promotes their admixture with the air. The space above the bridge is often, however, made too cramped with these ends in view. The narrower the space the greater must be the force of the draught to draw the gases through. The heightening of the bridge may, in consequence, be attended with an increased waste of fuel, as the gases are likely to escape at a higher temperature into the chimney. Moreover, the extent of the heating surface which receives the radiant heat from the fire is diminished by heightening the bridge, and the action of the higher temperature and more forcible impingement of the flame and air against the furnace plates is liable to be destructive, especially when sedimentary or greasy feed-water is used, or a seam of rivets happens to be near the bridge. The best height to make the bridge, in any case, can only be determined by actual trial, as it will depend upon the size of grate, strength of draught, character of fuel, thickness of fire, and relative quantity of air admitted through the bars and above the fire, or behind the bridge itself. The passage above the bridge, as an approximate rule, may be made one-sixth the area of the fire grate. By lowering the bridge the flame will not be cooled so suddenly by contact with the plates, and may be made to pass further along the flue with a diminished draught, whereby the prevention of smoke will be facilitated, the evaporative efficiency increased, and a saving of fuel effected. In many cases a reduction of two or three inches in the height and an improvement in the shape of the bridge, whereby it is better adapted to the shape of the furnace, have had a very marked effect in reducing the consumption of fuel, preventing smoke, increasing the evaporation, and in diminishing the wear and tear of the boiler.

Hanging or inverted bridges are often used. These are placed some two or three feet behind the ordinary bridge, behind which air is admitted to the gases. The space between the bridges then forms a suitable flame chamber for aiding the perfect combustion of the hydrocarbons, and the use of hanging bridges in this manner has been attended with very satisfactory results; but the difficulty of keeping them in repair has usually led to their abandonment after a short trial.

Underneath externally fired boilers with deep flash flues, two or three additional bridges are often arranged at regular distances between the furnace bridge and the back end of the flue for the purpose of keeping the gases in contact with the boiler as they pass along.

BOILER SETTING.

Boilers should be set with as little brickwork in contact with the shell as practicable, particularly at and near the bottom where any water or moisture is liable to lodge against the plates. All the flues should be faced with fire bricks, and fire lumps or blocks, but not bricks, should be used for the seating. No mortar should be used where it can come in contact with the plates, but fire clay should be used instead for the whole setting of the boiler. The flues should be sufficiently large to admit of being properly cleaned and to enable periodical external examinations to be made with facility and satisfaction. The common practice of cramping the flues arises out of the desire to improve the efficiency of the boiler by keeping the gases in contact with the plates. But the slight waste of heat that may result from the use of moderately wide flues is far outweighed by the greater security obtained from the better examination they invite. The fact is too often lost sight of that the difficulty of cleaning the plates caused by the narrowness of flues usually results in the plates becoming covered with a permanent coating of soot and other non-conducting substances, which renders them useless as heating surface, and consequently the narrowing of the flues defeats its own intended end.

Plain cylindrical or egg-ended boilers, when made with wheel draught or split draught, are supported on side walls which should not exceed three inches in width at the surface on which the boiler rests. There is, however, no advantage gained in evaporative effect by making the flues of long and moderately long egg-ended boilers for wheel draught or split draught ; but there is a decided disadvantage in the increased difficulty of cleaning and examining these arrangements of flues involve. These boilers are best set with flash flues, the gases passing straight from the bridge along the boiler bottom and sides to the chimney. This arrangement dispenses with all brick-work seating underneath the boiler, which is sometimes supported on cast iron brackets protected on their fronts by fire brick, but far more usually by brackets riveted to the sides and resting

upon the masonry. Boilers of great length—50 feet and upwards—are often suspended from transverse cast iron arches resting on the masonry at the sides and placed from 12 feet to 16 feet apart. The boiler is connected to each bearer by means of three bolts secured to angle or T irons riveted to the shell crown, and secured to the casting by nuts, by which the weight of the boiler can be adjusted. There should also be a strut of T iron across the inside of the boiler, under each bearer, to resist the tendency of the shell to assume an oval shape from the weight of the lower portion of the boiler and the water acting against the upward direction of the force exerted by the suspension bolts.

Since the weight on each bearer must vary considerably with the arching of the shell, due to the greater expansion or contraction of the bottom compared with the top, long boilers are liable to be strained and break their backs when suspended from the end attachments only, or the bottom is liable to become buckled together when suspended only from the middle bearers.

For remarks on the brickwork and setting of internally fired boilers, see chapter on Wear and Tear, p. 200.

With Cornish, Lancashire, and other similar boilers of moderate length, in order to promote the circulation, and heat the dead feed-water at the bottom, the flues should be arranged to conduct the gases forward underneath the shell bottom on leaving the flue tubes, the draught being split at the front to pass backward along each side to the chimney. Each side flue may be made with an independent damper, or one damper may be made to serve by uniting the side flues behind the down take at the back. But when the boiler is very short compared with the length of grate and there is a strong draught, it is advisable not to expose the shell bottom to a very high temperature by taking the gases along the bottom before passing through the side flues.

CHAPTER VIII.

INCRUSTATION.

ONE of the greatest, and at the same time one of the most frequent difficulties steam users have to contend with is the formation of deposit and incrustation, or, as it is also called, scurf, scale, or fur, in their boilers.

Where the scale does not acquire a greater thickness than about $\frac{1}{16}$ inch on that part of the boiler where the circulation is most defective, and not more than that of an egg-shell, where the circulation is most active, it may in most cases be regarded rather as an advantage than otherwise, forming, as it generally does a coating to protect the boiler against the corrosive action of the water. But when it becomes thick enough to threaten the closing up of the water spaces, or when it gathers in considerable quantities on the plates and tubes exposed to a great heat, the incrustation becomes a source, not only of annoyance and wasteful expenditure of fuel, but also of actual danger from explosion, and tends greatly to shorten the life of the boiler, even where no actual danger exists. The heat from the furnace not being carried off rapidly, as it otherwise would be by the fresh portions of water that are brought to it by the circulation, since its transmission is resisted by the thick coating of scurf, which is always a bad conductor, the plates become overheated, often to such an extent that they may in course of time become burnt through. The overheating due to the presence of incrustation may become dangerous, long before the plates suffer much from burning, especially in the case of large furnace tubes, where the softening leads to distortion which is soon followed by collapse and disaster.

The formation of incrustation, when it gives rise to slight overheating, must add materially to unequal expansion, which *is found to be* one of the principal sources of wear and tear *in a boiler.*

Incrustation also leads indirectly to overheating by closing up the apertures of the feed-pipe, especially when the water is admitted through small holes.

When of considerable thickness, and very hard and difficult to remove, incrustation interferes greatly with the examination of a boiler, and renders it no easy matter to ascertain with any degree of certainty the condition of the plates concealed from view. No doubt there are certain well-known marks of colour and configuration accompanying some kinds of incrustation which indicate with a considerable degree of certainty the defective condition of the underlying plates and rivet heads, but these indications are by no means infallible. Their presence often causes groundless suspicion and anxiety, and their absence may lead to a sense of security and consequent neglect likely to be productive of serious damage.

To such a degree does the accumulation of scurf interfere with the efficiency and safety of some descriptions of multitubular and water-tube boilers that their employment in many cases has to be abandoned. Indeed, the nature of the feed water available is too often lost sight of in making selection from different classes of boilers. It should always be understood, that when very bad or hard feed water is to be used, the boiler should be chosen for accessibility to all its interior parts, as upon this circumstance greatly depends its future economical and safe working.

Most waters used for stationary and locomotive boilers contain solid matters in solution which become precipitated by elevation of temperature, or are left behind by evaporation. On the matters ceasing to remain in solution, the first effect will be their deposition, and unless blown out sooner or later, the deposit becomes hardened, and forms incrustation. The quantity of matters held in solution are commonly from 20 to 40 grains per gallon, and in some few cases reach as much as 200 grains per gallon. But a much less quantity than the last is sufficient to cause serious inconvenience when present in boiler feed water. This may be easily shown as follows :—Taking the moderate quantity of 20 grains of mineral per gallon, of indifferent solubility, we shall have the considerable quantity of upwards of ½ cwt. left by the water boiled away in a week of 60 hours, at the rate of 350 gallons evaporated per hour—not a very unusual quantity with large stationary boilers. Taking the specific gravity of the incrustation formed as 3, one-half cwt. *will be sufficient to* cover 250 square feet of plate with

a thickness of ·0144 inch. This would amount to $\frac{3}{16}$ inch in three months, if allowed to accumulate.

With the customary want of attention to blowing out and cleaning, we can from this readily conceive the excessive thickness of incrustation that may accumulate over the whole internal surface below the water line in a very small fraction of the average life of a steam boiler.

Besides the substances held in solution many waters hold a large amount in suspension, which are left behind by the evaporation. These principally consist of mud, clay, and other earthy matters carried down by rains and running water, or stirred up in canals and rivers by the passage of vessels.

There are but few problems connected with steam engineering at which inventors have tried their hands to a greater extent than the prevention and removal of boiler incrustations. Of late years it is computed that not fewer than 200 patents have been taken out, and the number of anti-incrustation nostrums tried by confiding or desperate boiler owners is the best evidence of the magnitude of the evil they would overcome.

Before attempting to notice some of the various anti-incrustation schemes that abound, it is advisable to say a few words on the nature of the troublesome ingredients found in various waters.

The mere amount of solid matter in any water is no indication of its fitness or otherwise to be used in a steam boiler, as this depends almost entirely on the nature of the solid impurities contained. The presence of 50 grains per gallon of deliquescent salts, such for example as carbonate or chloride of soda would not be seriously felt with a moderate amount of attention to blowing off; whereas, on the other hand, an equal quantity of salts of lime would render the water unfit for use, unless an unusual amount of care and attention were bestowed on blowing out and cleaning the boiler. Unfortunately the presence of the former description of salts is the exception, whilst the latter is the rule.

The great majority of well, mine, river, stream, canal, and town supply waters contain sulphate of lime, bicarbonate of lime, and carbonate of magnesia. These, present in widely different quantities and along with various other impurities, are the principal ingredients in the waters that cause the *greatest* amount of trouble, by forming hard incrustations and *loose deposits* that retard the transmission of heat to the water.

According to M. Cousté, the following are the approximate

weights of different salts which one imperial gallon of water (70,000 grains) is capable of holding in solution when cold (60° Fahr.), and when boiled in the open air :—

	60°.	212°.
Carbonate of lime	merely traces.	merely traces.
Silica	70 grains.	,,
Sulphate of lime	175 grains.	,,
Carbonate of magnesia	3·25 oz.	,,
Sulphate of potass	10 ,,	40 oz.
Chloride of sodium	32 ,,	32 oz.
,, magnesia	266 ,,	580 oz.
Nitrate of calcium	500 ,,	?
Chloride of calcium	540 ,,	unlimited.

The order of deposition in the boiler as the water becomes concentrated is given thus :—1st. Carbonate of lime. 2nd. Sulphate of lime. 3rd. Salts of iron, as bases or oxides, and some of these of magnesia. 4th. The silica or alumina, usually with more or less of organic matter. 5. Common salt.

With respect to the salt water used in marine boilers, it is found to vary in density and in the nature of its ingredients in various localities throughout the globe. According to Dr. Ure, the largest proportion of salt held in solution in the open sea is 38 parts in 1000, and the smallest 32. The Red Sea contains, however, 43 parts in 1000 ; the Baltic, 6·6 ; the Black Sea, 21 ; the Arctic Ocean, 28·5 ; the British Channel, 35·5 ; and the Mediterranean, 38. Faraday found the average specific gravity of sea-water to be 1027, that of pure distilled water being taken at 1000.

The sea water used in his experiments weighed 64·1416 lb. to the cubic foot, and contained of

	oz.
Chloride of sodium	25·762
Muriate of magnesia	3·282
Sulphate of magnesia . . .	2·212
Sulphate of lime	1·013
	32·269

besides quantities of other salts too small to be noticed.

It is generally understood that the carbonate of lime, the same substance, *chemically* speaking, as selenite, chalk, marble,

and limestone, is held in solution, in fresh water, by an excess of carbonic acid, and that in reality it is present in the state of a bicarbonate. By heating the water, the excess of carbonic acid is driven off, and the greater part of the carbonate is precipitated. Its solubility diminishes as the temperature increases, and at boiling point it is scarcely soluble at all. It is for this reason that in water, from which the air has been expelled, carbonate of lime is found in such small quantities. Carbonate of lime has been variously estimated as soluble in from 24,000 to 16,000 times its volume of water, at ordinary temperature, or in the proportion of from $2\frac{3}{4}$ to $4\frac{1}{4}$ grains per gallon. According to M. Cousté, the solubility is nil at about 290° Fahr.

Sulphate of lime, a substance of the same chemical composition as gypsum or plaster of Paris, is next in importance to carbonate of lime. Its solubility also varies greatly with the temperature. According to Regnault, its greatest solubility is at 95° Fahr., when it dissolves in 393 times its weight of water, or in the proportion of 178 grains to the gallon. At 212° it is only soluble in 460 times its weight of water, or 152 grains to the gallon ; and according to M. Cousté, like carbonate of lime it is completely insoluble at about 290°. It is therefore evident that these two salts are precipitated in all kinds of water, merely by the elevation of temperature, when the boiler is worked at about 60 lbs. pressure.

In boilers working at low pressure, the sulphate of lime could be partially extracted by blowing off, if the water became saturated with it at about 230° ; but its solution requires time, and the rapid evaporation precipates it more rapidly than it can re-dissolve.

Carbonate of magnesia, or magnesian limestone, is the next important impurity in fresh water ; but it usually exists in much smaller quantity than the other two salts. In its relation to temperature, and in its behaviour in the water, it is similar to carbonate of lime.

On becoming insoluble the lime and other salts remain for a time suspended in the water, and tend to deposit themselves more or less rapidly, according to the density of the water, the manner in which it circulates, and the intensity of the ebullition. Over those parts of the heating surface where the water boils rapidly, the insoluble salts are held in suspension by the agitation until the ebullition subsides, or when the circulation is good they are carried away with the currents, until a comparatively quiet part of the boiler is reached, when they are de-

posited on the plates or tubes. It frequently happens that the feed pipe, itself when the feed is shut off, is one of the quietest spots in the boiler, and hence the amount of deposit often found in it. But the furring-up of the feed pipes, whether vertical or horizontal, is mainly due to the sudden precipitation of the impurities on being acted upon by the high temperature in the boiler. The manner in which the precipitation comes about is sometimes very remarkable, especially when the feed water at a high temperature enters the boiler nearly at the point of saturation. In such cases the lime salts are deposited as they pass through the apertures in the feed pipe, and gather fast and thick on the adjacent plates, or when the feed is distributed through a horizontal perforated pipe, the deposit is sometimes found projecting for a length of two or three inches from each aperture, like a hollow inverted stalactite. In time, the passage through the aperture gradually becomes closed up, and the feed is consequently prevented from entering.

It is by many supposed that the plates over the furnaces are most liable to become covered with a thick incrustation, as the greatest quantity of water is here evaporated. This is, however, seldom or never found to be the case unless the circulation is very bad, as, for instance, over the flat stayed crowns of most locomotive fireboxes. In plain cylindrical and internally fired tubular boilers the suspended matters in the water are driven off the plates by the ebullition, and carried to the part of the boiler where the circulation is most sluggish—generally the coolest part of the boiler—and are there allowed to deposit. When a considerable amount of incrustation is found over the fire in ordinary externally fired boilers, it is usually caused by the detached scale which has fallen from the sides of the shell, in pieces too heavy to be carried away by the circulation. The danger of overheating from this cause is one of the principal arguments against the practice of having a fierce heat under a boiler-shell, where the nature of the incrustation renders it liable to cover the furnace plates to any great degree.

The carrying away of the deposited matter by the ebullition and circulation is also retarded by the presence of grease or sticky matters in the water, which form a paste with the impurities that often proves too heavy or tenacious for removal by the currents in the boiler.

The sulphate of lime, on depositing, forms an amorphous crust, more or less hard, according to the other ingredients in combination with it, and the heat to which it is exposed. The

carbonate of lime and carbonate of magnesia, on the other hand, usually deposit as a loose fine powder, forming a white sludge with the water. They often solidify in combination with the sulphate, forming a hard amorphous crust. Before deposition, the light carbonates precipitated are held in suspension near the surface of the water, and are frequently carried along with the steam and water into the steam-pipes and cylinder. After a few months' work, pistons and cylinder covers have been found covered with a coating $\frac{3}{16}''$ thick, or even more, of this fine, impalpable powder. This, it is evident, in time, is liable to cause the breakage of the cylinder covers, pistons, or other parts of the engine.

When the deposited carbonate of lime is present in considerable quantity, along with other impurities, it will remain soft for a length of time, and if not exposed to too high a temperature when drying or emptying the boiler, will be converted into a fine floury powder, of a light colour. But if the boiler be blown out while the plates and brickwork in the flues are at a high temperature, the sludge often becomes baked hard ; and it is to this circumstance that a great amount of the hard incrustation from both the sulphate and carbonate of lime is due.

When a boiler fed with water containing salts of lime is blown out cold, and the interior is examined before it becomes dry, the plates, tubes, and stays may be found covered with a thick coating of light-coloured sludgy deposit, that can be removed with very little trouble if brushed off or washed out with a hose-pipe and jet of water. Should, however, the interior be maintained at a high temperature, by blowing out before the boiler and flues are cool, the deposit becomes baked on, and apparently there is not so much left for removal where the practice of chipping off the scale is not carefully carried out. It is for this reason, namely, the excuse of having little easily removable deposit to deal with, that many boiler attendants prefer allowing the scale to bake hard and fast on. It must be admitted that in many tubular boilers the task of sweeping or washing out the loose deposit is a very unpleasant one, and likely to be shirked by the majority of boiler attendants.

Various attempts have been made to calculate the loss of heat caused by incrustation formed on the heating surface. But the circumstances to be considered which determine the rate of heat transmission through plates covered by scale of different *kinds and thickness*, either homogeneous or otherwise, are not *sufficiently* well understood, and are too numerous to admit of

anything like exact calculation. It has by one observer been stated that $\frac{1}{16}$ inch of incrustation on the tubes of a multitubular boiler is equivalent to a loss of 20 per cent. of fuel, and that the loss increases in a very rapid ratio.

Another observer has demonstrated that a scale $\frac{1}{16}$ inch thick demands an increase of 15 per cent. of the fuel, and as the incrustation thickens the ratio increases thus: when it is $\frac{1}{4}$ inch thick 60 per cent. more fuel is required, at $\frac{1}{2}$ inch 150 per cent., and so on. Now it is not stated with which particular kind of boiler, or for which part of the boiler this statement holds good, nor is the nature of the incrustration stated, on which its conducting power depends. Most boilers with an ordinary draught would be quite unworkable with $\frac{1}{2}$ inch of scale on the furnace plates, and numerous boilers have scale considerably thicker than this over the greater portion of their heating surface, without demanding anything like 100 per cent. more fuel than when the plates are clean. On the other hand, it has been stated, on the authority of Peclet, that a very thin coating of incrustration favours the transmission of the heat to the water, since it has been observed with new locomotive boilers, that the production of steam increases at first, then remains stationary, and at last decreases. It is probable, however, that the increased production of steam observed was due to the diminution of the priming which is generally very great in new locomotives, and which decreases as the grease and dirt are removed, and as the violent ebullition at the firebox diminishes when it becomes covered with a thin coating of scale.

It is certain that the uniform coating of sulphate of lime formed hard and fast on the furnace plates even $\frac{3}{16}$ inch thick, is not so liable to lead to overheating as the thinner, but more irregular deposits, that sometimes form like barnacles on the plates over the fire, or the scale formed of lime salts mixed with organic matter which adheres tenaciously, but does not lie close to the plates. Indeed, a few greasy rags lying on the plates exposed to the fire will lead to overheating sooner than a formidable-looking mass of close-lying and compact incrustation. But the deposit that produces most frequently the effects of over-heating where they are often least expected, and by many considered most unaccountable, is the impalpable powder found in the boiler when empty and dry, of which carbonate of lime is the chief ingredient. In consequence of the lightness of its particles it is *long held in suspension*, and covers the surface of water as a

scum. When the water becomes saturated with this substance, great resistance is offered to the free escape of the steam bubbles, and to the free convection of heat. The water is in consequence lifted off the plates by the steam that accumulates on their surface, and allows them to become over-heated.

The tendency to over-heating is much aggravated, if grease or other organic matter be present in the water along with this fine floury deposit. The grease appears to combine mechanically with the carbonate of lime, and when the compound sinks on to the plates overnight, or when the boiler is at rest, it clings as a loose, spongy mass, too inert to be carried off by the circulation or ebullition which it retards, and by preventing the contact between the plates and the water, and by offering great resistance to the transmission of heat produces over-heating of the plates.

The floury deposit usually consists of at least 60 per cent. of carbonate of lime with small quantities of carbonate of magnesia, sulphate of lime, oxide of iron and alumina, sand and other impurities. Its colour may be white, grey, slate colour, or fawn colour. When found in the boiler after blowing off, the colour depends in great measure upon the heat to which it has been exposed, being lighter on the furnace plates, and those over the hot brickwork, than upon the stays and upper parts of the boiler. Being easily washed out as sludge when the boiler is damp, or swept away as fine dust when dry, the presence of this deposit often attracts too little attention, and is often overlooked as a cause of over-heating. Its presence is usually made manifest by leakage at the seams and fracturing of the plate edges over the fire, frequently accompanied by a gradual and steady depression of the furnace plates both in externally and internally fired boilers. In Cornish and Lancashire boilers the over-heating is not so much at the crown as at the sides of the furnace where the plates frequently bulge inwards a few inches above the fire bars, the crown being at the same time forced upwards. The presence of grease in combination with the deposit is easily recognised by heating a small quantity on a red-hot plate, or in a ladle. Grease is nearly always present when the feed is heated by the exhaust steam from a non-condensing engine, or is drawn from the hot well of a condensing engine. In many cases the system of feed heating by the exhaust steam, or feeding with water from the hot well has to be abandoned in consequence of the injury done to the boiler by the grease so introduced.

The tendency to over-heating when this carbonate of lime or carbonate of magnesia powder is present is naturally much increased when the furnace heat is intense, either from the nature of the coal or the strength of the draught, or from the closeness of the fire to the plates. In fact a very slight increase of draught from a difference in the setting of the boiler and arrangement of damper, firebars, or bridge, may make a decided change in the liability to over-heat. Cases have been met with, where, in a series of boilers apparently alike in every respect, only one has given trouble from leaking, fracturing, and other effects of over-heating, and it is always found that this boiler burns the most coals, either from having the best draught, or from the fires being forced in consequence of the bridge being too high. When the rate of fuel consumption is reduced to that of its neighbouring boilers, the trouble from over-heating is found to cease.

That a compact homogeneous mass of incrustation should prove less detrimental to the plates exposed to the action of the fire than a spongy, less solid, or powdery mass, is easily accounted for on the principle that loose sand forms a much worse conductor of heat than the solid stone from which it has been reduced. By way of illustration it may be remarked that if we take a kettle or pan, coated inside with ¼ inch of scale, we can boil clean water in it with far less risk of over-heating than if we take a clean vessel and attempt to boil milk or water thickened with oatmeal, or other like substance.

In the latter case in consequence of the accumulation of the steam bubbles on the bottom of the vessel, and the resistance opposed to the convection, unless it be promoted by stirring, the bottom of the vessel will soon become over-heated, the effect of which is well known to those experienced in culinary matters.

On breaking a piece of hard incrustation taken from the bottom or sides of a boiler, the fracture generally presents a series of layers, partly crystalline and partly amorphous. The layers are of different thickness, from that of paper to ½ inch or more. Interspersed with these hard layers formed by the deposition of the salts, are frequently found thin soft layers of earthy matter, which has been held in suspension and deposited when the agitation of the water has temporarily ceased. It sometimes happens that not two of the numerous layers are alike in colour, consistency, or chemical composition, a fact due to the *disturbing influence* at the source of the feed supply. The

face of the incrustation next to the plate is very often of a black colour, and adhering to it is found a film of oxide of iron, whilst the surface of the plate is quite soft, and bears unmistakable signs of wasting, sometimes to a considerable depth. This is usually caused by the corrosive action of the iron salts, and in brackish water by chloride of magnesia (muriate of magnesium). This last salt is the destructive agent in sea water. When concentrated it decomposes at 212°, according to Faraday, forming magnesia and hydrochloric acid. The latter on being set free rapidly corrodes the iron.

From water containing salts of iron in considerable quantity the incrustation formed has often a red tinge. Chalybeate waters are generally highly injurious to the plates, and the film of incrustation next to the iron is sometimes of a deep red, colouring the water that comes in contact with it through the fissures in the scale, by which the presence of these injurious salts of iron is easily detected. Some kinds of the softest and purest waters deposit small scales in a somewhat curious manner over the plates about $\frac{1}{8}$ inch thick, of irregular shape from $\frac{1}{2}$ inch to 1 inch diameter. On removing these the plate is found corroded underneath sometimes to a considerable depth.

The means in use and proposed for preventing and removing incrustation may be classed as follows :—

1. Blowing off.
2. Introduction into the boiler of chemical agents, to render the impurities in the water more soluble.
3. Introduction of mechanical agents calculated to prevent the accumulation of the deposited particles into a solid mass, and to diminish their adherence to the plates and tubes.
4. The employment of internal collecting apparatus, from which the deposit can be removed more readily than from the plates and tubes.
5. The improvement of the circulation by braticing or separating the upward and downwards currents by plates or tubes.
6. Purification of the water previous to its delivery into the boiler by heating, treating with chemical re-agents, or filtration.
7. Surface condensation.
8. Cracking off the incrustation already formed by suddenly *expanding* or contracting either the scale or the plates.
9. Removal by manual labour.

10. Employment of galvanic or other agents whose action is not understood.

11. Allowing the boiler to cool slowly and completely before blowing out.

1. Blowing off is the readiest, and therefore the most frequently used means for both the prevention and removal of incrustation. In most land boilers the blow-off tap is only in communication with the boiler bottom, and in most cases its effect is too much localised to be of any great value as a preventive of incrustation. But there are many boilers provided with one or more internal pipes, extending from end to end along the bottom, and in connection with the blow-out tap. These pipes are usually carried about 1½ clear of the plates, and perforated on their under side, where the holes are not so liable to choke up as on the top. The common practice is to use this bottom blow-out apparatus twice or thrice a day, with the boiler at work.

When this apparatus is kept in good order, experience has shown it to be of marked value where the impurities are heavy and sink to the bottom. But when the water contains much carbonate of lime and carbonate of magnesia, and other ingredients of light weight, it is found better to blow off after the boiler has been for some length of time quiet, and the deposit has had time to settle.

Perhaps the best indirect proof of the efficiency of the bottom blow-out apparatus is shown in the liability of the blow-out pipe to become completely furred up if not regularly used, when it renders the emptying of the boiler no easy matter.

The fact of the impurities in many boilers being held in suspension for some time by the agitation of the water after they cease to be soluble, and floating as scum on the surface, has suggested the plan of using surface blow-out apparatus. Several arrangements of this kind have been invented and are extensively used. They are all alike in one respect—they offer a quiet place, free from the agitation caused by the ebullition, for the deposit to settle in. The deposit that collects is blown out at intervals.

One arrangement, at one time much used, consists of one or more trumpet-shaped mouthpieces, in which the scum collects, placed in communication by vertical pipes with the horizontal bottom blow-out pipe. The mouth is best placed horizontally *across the boiler*, and facing the front end to meet

the surface currents, which always set backwards from the fire. This arrangement is very objectionable when applied to most descriptions of internally fired boilers as the pipes, both horizontal and vertical, greatly increase the already very arduous task of cleaning out the boiler bottom. It very frequently happens that this interference with the sweeping out and cleaning produces a greater evil than it seeks to remove, and no permanent advantage can be expected from the introduction of pipes or other obstacles along or near the bottom of Cornish, Lancashire, and similar kinds of boilers.

In order to act with equal efficiency as the water level rises and falls, apparatus have been introduced to float on the water, but the incrustation interferes with their freedom of action, and in many cases they soon become fixtures.

Another surface blow-out apparatus consists of a 3-inch or 4-inch pipe, with a trough cast on its upper side, communicating with a blow-out tap, usually fixed on the boiler front. This, cast in short lengths to admit of being passed through the manhole, extends from end to end of the boiler, and is fixed so that the top of the trough is just about one inch below the mean level of the water. In order to be most effective, such an apparatus should be placed in the middle of the boiler, but here it would greatly interfere with the cleaning of many kinds of boilers; and for this reason, and also for facility of fixing, it is usually placed on one side. It is usual to have only one pipe in ordinary sized boilers, but two would answer better in a boiler sufficiently large for their admission without interfering too much with the cleaning out.

The single surface blow-out apparatus, just described, has been extensively, and in very many cases successfully, used. In some cases, however, it has fallen into disuse and been abandoned, in consequence of the little additional amount of labour necessitated in keeping clear the perforations along the top of the pipe, without which they are liable to become choked up, which renders the apparatus worse than useless, as it must always interfere with the free access to some part of the boiler. The plan of keeping the perforations clear by introducing the feed through them has been patented, and has given satisfactory results. Since it is absolutely necessary that the feed inlet should be kept clear, this plan ensures the requisite amount of attention being paid to the blow-out apparatus.

An objection sometimes raised against surface blowing out is *the waste it* causes, which is stated to outweigh any small

advantage it may afford. It may happen that the waste in blowing out the hot water may be greater than the loss arising from the deposit it is sought to remove. This will, however, depend upon the manner of using the apparatus, and as this is a matter of some importance, we will consider the principles on which its efficiency depends.

If the deposits were produced merely by the concentration of the water, that is, if they were precipitated only on the water arriving at the point of saturation; and assuming the concentration to be uniform throughout the boiler, incrustation could be almost completely prevented by blowing off from any part below the water level. In this case it would only be necessary to extract a quantity of water containing a quantity of salts equal to that contained by the feed introduced. If the feed contained 1 per cent. of any salt, and it required 3 per cent. to saturate it, there would be no precipitate if one-third the quantity of water introduced were blown out, the water in the boiler being thus maintained below the point of saturation. Ordinary sea water contains about $\frac{1}{32}$ of its weight of common salt. As the brine in the boiler should never be allowed to exceed treble that strength, the volume discharged should be equal to half the volume of water evaporated. In many cases it is inadvisable to allow the brine to rise above double the strength of ordinary sea water, or to exceed $\frac{2}{32}$ of saltness; the brine discharged should then be equal in volume to the nett feed water, or the quantity evaporated. The loss arising from blowing out is given at page 308.

It is evident that the beneficial results obtained from blowing out the brine at sea would always be produced with the other deposits if they were suspended equally throughout the whole body of water in the boiler on ceasing to be in solution. Unfortunately, however, nearly all the matters excepting the salts of soda are precipitated by the mere elevation of temperature, and are no longer in solution at ordinary working temperatures. The heavy sulphate of lime deposits, the most troublesome to remove, are not long held in suspension. It is, therefore, useless to rely upon blowing out a large quantity of water to prevent the formation of sulphate of lime scale. The lighter particles of carbonate of lime, which are longest held in suspension when the water is in agitation, although in great measure removable by surface blowing out, are not readily extracted by blowing out a large quantity of water at long intervals, as many suppose. Careful observation has

shown that when either a surface or bottom blow-out tap of a land boiler is opened, the deposited matters that have gathered in the pipes are copiously discharged all at once. In ordinary cases their flow does not last longer than from 5″ to 10″. Unless highly soluble salts, as those of soda, are present, the water discharged after this contains but little incrustation matter, and the blowing out is therefore only a waste. The proper manner of using blow-off taps, where the object is to extract the lime and magnesia salts, is to open them at least every hour, or as soon as the deposit has had time to accumulate in the pipe, for about 10″ or 12″ at a time, rather than for 60″ or more every three or four hours, which is the prevailing custom. This practice will doubtless cause a greater amount of wear and tear of taps and packing, and will demand more attention than is usually given.

2. The number of chemical substances introduced into boilers with a view to increase the solubility of the contained salts, by decomposing them, is very large, and their use has been attended with widely varying degrees of success.

Perhaps the most extensively employed of these substances, since it is the cheapest as well as one of the most effective, is carbonate of soda—the common soda of commerce. White ash, or soda ash, being cheaper, is often used instead, but is less effective. Soda is found to act well in preventing and removing incrustations, consisting of both sulphate of lime and carbonate of lime. The manner in which the soda and the sulphate in the water react on each other is readily understood. These two salts exchange their acids, the result being the formation of sulphate of soda, which is very soluble, and carbonate of lime, which, being absent from any carbonic acid in excess, is insoluble, and precipitates without forming a hard incrustation. The reaction on the bi-carbonate of lime contained in the feed water leads to the same result—the precipitation of the lime salts. The carbonic acid in excess is seized upon by the soda salt, and the carbonate of lime is very rapidly precipitated. The carbonic acid taken up by the alkaline carbonate is however liberated again by the heat, and the soda is in its original state, and ready to act again as before. This is probably the reason why a very small quantity of soda is found to act with such effect in a very large quantity of water.

The carbonate of lime, after settling, which it does most *quickly in* the quietest parts of the boiler, remains for the most *part* as sludge that can be easily washed out, as has already been

stated, and therefore the boiler should be cooled gradually, and not emptied whilst the brickwork and plates are still hot enough to bake the sludge into a hard incrustation along with the sulphate of lime usually found with it. Before settling, this precipitate, in consequence of its minute division, is carried by the agitation of the water to the surface, and remains for a time as a scum, although the specific gravity of the solid carbonate is about 2·7. For the above reason, when lime salts are present in any considerable quantity, the use of soda should always be accompanied by frequent and regular blowing out, to prevent priming, and the overheating that is liable to take place from the thickening of the water, or from the settling of a large quantity of deposit on the furnace plates when the water is allowed to become quiet—as at meal times.

The common practice of introducing the soda is to empty a bucketful, or other quantity, in the solid state, through the manhole when the boiler is filled and ready to start after cleaning, or else to drop it periodically, at intervals of a few days, through the safety valve, when the steam pressure can be allowed to fall. Now, there is one great disadvantage in thus introducing soda into a boiler in considerable quantity at a time, namely, the tendency it has to cause priming and all its accompanying evils, even to the breaking of cylinder covers, &c. The liability to cause mischief from the injudicious use of soda has frequently led to its abandonment, and, like many other useful agents, the evils attending its abuse are worse than the evils its judicious employment would remove.

The plan of introducing the soda into the water tanks or hot-wells of condensing engines from which the boiler is fed cannot be recommended, as a great quantity of the water usually runs to waste, and consequently no proper estimate can be formed of the quantity of soda that actually reaches the boiler. The best method in all cases is to dissolve the soda, and introduce it continuously with the feed, which can be done by connecting the vessel containing it with the suction pipe of the pump that supplies the boiler. The rate of flow can be regulated by a small tap between the suction pipe and the vessel containing the soda. When the boiler is fed with an injector, there should be a small tank from which the feed is drawn, in which the soda can be dissolved. This tank should be drained by the injector from time to time, to insure the introduction of all the soda into the boiler. The proper amount of soda to be used is best found by experience. The usual quantity varies from 1 lb. to 2½ lbs.

per day, according to the quality and quantity of the water evaporated. With soda ash a larger quantity will be required, and with caustic soda a smaller quantity.

When used in excess, soda is by many considered to destroy the engine packing, and to attack the brass work below the water level, such as the water gauges and other mountings on the boiler front. There can be no doubt that the brass taps and valves often require more frequent regrinding to keep them tight when soda is used in the boiler. This, however, may be attributed to the increased amount of fine grit and powder caused to float on the surface, which acts rapidly on the brass wearing surfaces, and is another reason why an efficient surface blow-out should be provided when soda is used in water containing much carbonate of lime.

Soda does not act injuriously on the boiler plates, unless the salt is concentrated from want of sufficient blowing off, or unless the soda itself is impure, and contains acids. Yet it has often been charged with causing internal corrosion in all its various forms. The belief in its injurious action has in many cases arisen from the following cause. In boilers fed with water containing corrosive impurities, together with matters that form a thick incrustation, the damage done by the former is in time to a great extent prevented, and sometimes altogether concealed by the scale formed. On employing soda, and particularly caustic soda, to remove the incrustation, the defects in the plates, whose presence may not even be suspected, become exposed, and being attacked anew by the acids in the water used for washing out the boiler, which are not neutralized by the soda, are caused to "bleed." This gives them the appearance of having been recently formed, and their presence is at once set down to the action of the soda.

This leads us to the consideration of another valuable property of common soda, namely, its power of neutralising the free acids so often found in the purest waters used for boiler feeding, as well as in those containing large quantities of impurities, and which are the direct cause of pitting and other forms of corrosion. The introduction of about half a pound of soda per day into an ordinary large-sized boiler is generally found sufficient to prevent, or at least to greatly mitigate, any corrosive action.

The well-known property soda has of dissolving and removing *grease, which* constitutes one of its chief values when used for *domestic purposes*, renders it very useful in overcoming the

difficulty often caused by the presence of grease in the water. The foaming up of the water is increased by the addition of soda when grease is present. This, if allowed to take place to any great extent, is liable to give trouble by priming; and again, on this account, a scumming apparatus or surface blow out should be used whenever soda is used with greasy water.

The low price of soda-ash leads to its use instead of common soda; but it is often sold in a very impure state, and mixed up with other matters whose introduction into the boiler had bette be avoided.

Caustic soda is also used, but is said to have a slightly corrosive action when concentrated. It removes hard sulphate of lime incrustations more rapidly than common soda, and should be employed in smaller quantities. Its use should always be accompanied with frequent blowing off.

Potash, or carbonate of potassa, acts with salts of lime and magnesia nearly in the same manner as common soda. Carbonate of ammonia acts similarly on lime salts, but does not precipitate magnesia.

Chloride of barium or muriate of baryta decomposes sulphate of lime, forming sulphate of baryta, which is precipitated. The chloride of calcium or muriate of lime left behind is very soluble, but when allowed to become concentrated is liable to lead to corrosion.

The above, and many other chemical compounds, have been recommended for the prevention of incrustation, but as none of them can compare, commercially speaking, with soda, they are not likely to be much used.

Catechu, nutgalls, and other astringents containing tannic acid, have been found effective in preventing and removing incrustation. The tannic acid decomposes the lime salts, and forms tannate of lime, which is insoluble at first, and forms a scum which should be removed by surface blowing off. The remaining soluble constituents should also be blown off frequently, as their concentration is liable to tell severely on the iron unless the acids be neutralised by sufficient alkaline substances purposely introduced. Where tannic acid is found to act well, perhaps the best mode of supplying it is to suspend in the boiler a log of oak wood with the bark on, from which the acid is gradually extracted. In all cases where tannic acid is used, its effect on the plates and tubes should be carefully watched.

Sal-ammoniac, or muriate of ammonia, has also been successfully used for preventing and removing incrustations, consisting chiefly of carbonates of lime and magnesia. The chlorine contained in it forms with the lime chloride of lime, which is soluble, and can be got rid of by blowing off. The remaining compound, namely, carbonate of ammonia, is soluble, and also volatile, and may pass off with the steam ; but when it becomes concentrated, it attacks the plates and brasswork about the boiler, and on this account the use of sal-ammoniac is said, in many cases, to have been abandoned.

For removing incrustation already formed, hydrochloric or muriatic acid has been recommended. It is usual to introduce it before the boiler is cooled down previous to cleaning. It dissolves the deposits of carbonates of lime and magnesia, forming the soluble chlorides of lime and magnesium, which pass away with the water on emptying, or being in a state of sludge can be readily washed or swept out. Unless used with very great care this acid is very liable to attack the plates and tubes seriously, and on this account its employment cannot be recommended. Arsenical and other compounds have also been recommended and used in a limited degree. One important circumstance in connection with the employment of these substances should be noticed. On account of the expense attending their use it is too often recommended not to blow out the water from the boiler for a length of time, during which the boiler is working, in order to get the utmost benefit from the ingredients. The effect of this is to thicken the water to such a degree by the concentration of solid matters as to endanger the safety of the boiler from overheating.

It frequently happens that there is a choice of two waters for feeding the boiler ; the one a spring or brook, containing ingredients that form a hard incrustation, the other a surface water containing peatly or other acid substances, which act injuriously on the plates, but at the same time dissolve the calcareous matters deposited by the first. In such cases it is found of great advantage to play one water off against the other, the hard water being used first to protect the plates, and the other afterwards to remove the incrustation formed.

The use of chemical substances for preventing and removing scale by rendering it soluble is most required in boilers inaccessible for hand cleaning, or for the solution of large fragments of *scale that* have been loosened or detached by agents that act *mechanically* ; and as such boilers cannot be well examined

internally, the greater care is necessary not to introduce anything into them that is liable to injure the plates.

3. The substances used to act mechanically in preventing and removing incrustation by decreasing the cohesion and adhesion of the deposited particles, are even more numerous than those employed to act chemically in decomposing and dissolving the solid matters. In fact it is difficult to mention any common commodity that has not been employed to prevent incrustation in one way or the other, although the manner in which different substances may act is often not understood by those who employ them.

The substances that act mechanically may be divided into two classes, namely, first, those that envelop the precipitated solid particles in a glutinous or slimy coating, which prevents their adherence to each other, and to the plates and tubes; and, secondly, those that act by diffusion among the particles, so as to prevent their cohesion by interposition. Belonging to the first class are such articles as Irish moss and some other species of marine algæ, potatoes, tallow, oil, starch, linseed, sugar, molasses, stearine, gum, dextrine, and a host of similar ingredients. Flitches of spoiled bacon have been cut up and put inside boilers, bones and all. In a few instances whole dead carcases of pigs, dogs, rabbits, and other animals, have been introduced, with the object of boiling the fatty matters out of them. The danger of using such expedients as those last enumerated need not be dwelt upon. However well the use of greasy substances may have been found to answer in individual cases, it has nevertheless been the cause of an immense amount of trouble. It has already been pointed out that grease is a source of danger in a boiler, and on no account should it be used, especially when the feed water contains carbonates of lime and magnesia. The majority of the above substances are largely used in different countries; and the benefit resulting from their employment in many cases cannot be disputed. But the common practice of introducing lumps of tallow and other substances cannot be too strongly condemned. The tallow of commerce varies considerably in its nature, and in its behaviour inside a boiler. It is usually assumed that it melts immediately the water becomes hot, but there are numerous instances of large pieces of unmelted tallow having been found inside a boiler after working for two months at 40 lbs. pressure or more. In some cases the tallow seems to change its nature on becoming permeated by the steam. It sometimes combines with the calcareous

matters, and forms into small round balls, by being rolled about the boiler bottom. These are easily removed when the boiler is cleaned out, but are liable to cause trouble if they lodge on the furnace plates. The tallow appears to combine with the lime salts, forming an insoluble soap, which will remain for any length of time unaltered in the boiler. The introduction into a boiler of some of the glutinous substances mentioned has sometimes a wonderful effect in detaching large pieces of incrustation that can only be likened to flags. The greasy matter insinuates itself in an irresistible and curious manner between the layers of scale and the plates, and the variations of temperature or a few blows with a hammer complete the detachment. Some of the more viscid substances act better than oil in this respect : they appear more searching and tenacious.

Belonging to the second class are clay and similar substances, which are mixed with water and introduced along with the feed. Mixing intimately with the other solid particles as they become disengaged, the clay prevents their cohesion. This action is, however, by no means certain, and it is obvious that this expedient only adds to the solid matters held in suspension, which too often find their way to the engine cylinder, and are very liable to settle upon the furnace plates when the damper is closed and the boiler is quiet at meal times and over night. Experience has proved the disadvantage of this method, and it is now but very rarely employed. Colouring matters, such as logwood, are found to act in a similar manner to the above in preventing the cohesion and accretion of deposit. They are introduced either in the form of powder or chips. In the former shape, however, the substance is likely to cause trouble at the cocks and valves.

In order to prevent the adhesion of the deposited matters, it is a common practice to smear the plates and tubes over with slimy or oily mixtures every time the boiler is emptied and cleaned. A favourite mixture consists of tallow, blacklead, and soft soap; railway grease and other similar substances being sometimes added. Provided the coating of grease is thin, and laid carefully on with a brush, it is far less objectionsble than the introduction of grease into the boiler in large pieces, or even in a fluid state, when it is always liable to stick to the plates and cause overheating. There are many cases where boilers fed with water containing sulphate of lime have been kept very free from incrustation when the smearing is frequently and carefully carried out.

There is yet another way in which foreign particles added to the feed water, and which have no tendency to cohere or conglomerate, act in preventing the hardening of the incrustation on the plates. They form nuclei, round which the particles of lime and other salts collect before they subside. These centres of deposit do not readily agglomerate, and can be easily removed by washing out. Sand, and sawdust of different kinds of wood, but principally mahogany, have been used with this object. The great objection to this method in some cases is the liability of the small foreign substances to be carried over into the cylinders, and there cause trouble; and the employment of such a substance as sawdust is not conducive to safety and convenience in working the taps and valves about the boiler.

A great number of the proprietary anti-incrustation compositions act mechanically, others depend upon a chemical action for their alleged efficiency, whilst a few aim at supplying both modes of action for the prevention and removal of incrustation. These compositions are often sold as being efficacious with *all* kinds of water. The possession of any such efficacy is scarcely worthy of emphatic denial. A composition that may act beneficially in one kind of boiler, and with a certain water, may prove actually dangerous when used under different conditions of boiler arrangement and water. The remark may be here repeated, that with a view to prevent wasting any of the composition, often purchased at an exorbitant price, a recommendation is frequently given not to blow off the boiler for some time, perhaps a week, after the composition is introduced, in order that it may be used to the greatest advantage. This advice should never be followed, as the bottling up of a boiler for a length of time, and thereby concentrating a large quantity of carbonates of lime or magnesia, in combination with greasy or glutinous matters, is attended with great risk of overheating. There is also another consideration which should not be overlooked: the purchase of these nostrums has often an indirect tendency to make matters worse rather than to improve them, for their certain efficacy is so highly lauded by the vendors that the boiler attendants think they have nothing else to do than introduce the composition according to directions, and spare themselves all further trouble of carefully removing the scale by chipping or washing out when the boiler is periodically emptied. The result of this is annoyance, expense, and actual danger. Instances may be cited where the purchase of a well-known anti-incrustation compound to the extent of nearly

£200 per annum has only resulted in shortening the life of the purchasers' boilers by 50 per cent.

4. Besides the bottom and surface blow-out apparatus, the plan has also been tried of suspending in the boiler independent vessels of various descriptions, blocks of wood, pieces of sheet iron, and other suitable contrivances for the deposit to settle upon instead of upon the plates. These can be taken out of the boiler and the scale removed by hammering, or cracked off by sudden expansion and contraction. This principle is most fully carried out in the method, which has been to some extent adopted, of lining the boiler shell with a series of short lengths of plate, which are kept a few inches distant from the boiler by suitable distance pieces, forming, in fact, a duplicate bottom and sides, which terminate a few inches below the water level. By this means the passage for the escaping steam particles and ascending current of water is contracted, and the rapidity of the circulation increased in proportion. The solid matters carried by the circulation over the top of the plate are deposited on the inside lining, where the water is comparatively quiet, whence they are removed bodily with the lengths of plate through the manhole. It is obvious that this plan is most applicable to plain cylindrical boilers. The objection to it appears to be the difficulty it offers to cleaning and examining the boiler plates when the casing becomes too thickly coated with a hard incrustation to admit of ready removal and replacing, which it will inevitably do in course of time, with very bad feed water, unless care be taken that the boiler is not cooled down rapidly previous to emptying for cleaning. So long as the boiler is gradually cooled and emptied cold much of the deposit will remain soft, in which state it would also be found, at least to a great extent, under the same conditions without the casing.

5. The prevention of the deposition of the solid matters where they would prove troublesome, is effected by improving the circulation of the water either locally or throughout the boiler by the method last noticed, and other similar devices, as well as by the addition of water tubes in Cornish and Lancashire boilers. There are several patented arrangements of tubes for improving the circulation and increasing the amount of heating surface in boilers of limited size, which are said to remain free from scale by virtue of the circulation maintained within them. This is true with moderately good water, and *where they* are well attended to, but with very bad feed water

and ordinary attention most kinds of "improved circulation" tubes will be found to give trouble.

6. The employment of external collecting vessels in which the calcareous and other matters are deposited previous to the entrance of the water into the boiler has long been in vogue as a preventive of incrustation. The carbonate of lime may be precipitated in close or open vessels or in pipes, by the application of the waste heat from the boiler, or by heating the water with the exhaust steam. In order to throw down any considerable quantity of sulphate of lime, the water must be very highly heated, and pipes placed in the flue may be employed. It is evident that this is only removing the annoyance one degree, as the incrustation which forms in the secondary vessels in its turn requires removal. It is on this account that this mode of purification is not more extensively adopted. It must, however, be urged in favour of this system that when the calcareous matters are extracted in sufficient quantities to keep the boiler in a satisfactory condition, the danger from overheating should be removed.

Dr. Clark's well-known process of purification comes under this head. Instead of applying heat, this method consists in adding a measured quantity of lime in solution to the water containing bicarbonate of lime. The added lime combines readily with the carbonic acid, and the resulting carbonate of lime is precipitated along with the disengaged carbonate which was held in solution as a bicarbonate.

When the water contains also sulphate of lime, this may be subsequently precipitated by the addition of soda salts. Indeed, both the lime salts could be precipitated in a single process by a solution of carbonate of soda, but the double process would probably prove less costly in the long run. In these chemical processes the water should be analysed, and the proper amount of lime or soda to be added determined by actual test. Where the quantity of lime salts varies considerably at different times, these chemical processes are scarcely applicable, in consequence of the number of tests necessitated to arrive at the proper quantity of lime water to be added. Clark's process has been employed to some extent with success, but it appears too delicate in its application to come into general use. When completely carried out, the purified water requires filtering, and this necessitates the employment of two or three separate tanks, and an amount of attention which is not easily obtained. It is probably only where the water available is so bad as to be quite

unfit for use that this system is employed. The space occupied by the external collecting vessels and their additional weight, renders the plan inadmissible in many cases. It may be remarked that many of the anti-incrustation compounds might be applied with more advantage and less danger in external purifying vessels than in the boilers.

7. In those cases where the feed water holds much foreign matter in suspension, usually in the form of sand or clay, it is advisable to resort to filtration, by forcing the water upwards through a series of layers of pebbles, bones, or other suitable materials. These, in their turn, require frequent cleaning, which is usually best effected by turning on a current of steam or hot water through them as often as found necessary.

8. The system of surface condensation, found so efficacious with salt water in sea-going steamers, has made remarkably little progress in its application to land boilers and condensing engines.

This system consists in passing the steam from the cylinders in one direction over the internal or external surface of a number of tubes, where it is condensed by contact with the surface, cooled by a stream of water (or, more rarely, by a current of air) passing continually in the other direction and on the other side of the tubes. The condensed steam is thus rendered capable of being used continuously over and over again in the boiler. There can be no doubt that this method could be applied with advantage in using many descriptions of water acidulated, or impregnated with salts that cause trouble in the boiler.

It has been found that very pure or distilled water acts injuriously on the plates, and in most cases where surface condensation is used it is advisable to allow the internal surface of the plates and tubes to become covered with a very thin coating of incrustation, in order to protect them from the corrosive action of the water. This coating, in some cases, it will be found necessary to renew from time to time by using a certain quantity of water containing lime-salts, which it may be necessary to supply artificially.

In some surface condensers the side of the tubes in contact with the steam is found to become coated and clogged with grease. This can be best removed by washing with an aqueous solution of soda or potash.

In using sea water for surface condensation no trouble is

likely to arise with the water side of the tubes; but in using fresh water, containing bicarbonate of lime, the elevation of temperature will cause the precipitation of the lime salt, which will rapidly incrust the surfaces it comes in contact with, and so impair the efficiency of the apparatus. It is, perhaps, on this account that surface condensers are not so applicable to many kinds of fresh water as to sea water.

It has also been found that the grease carried over from the engine cylinders, in using the condensed steam unchanged for a lengthened period, acts injuriously in pitting the plates and iron tubes of the boilers. This defect has been ascribed by many to the decomposition of the grease and tallow by the protracted action of the steam and hot water, by which a fatty acid is formed that attacks the iron where the grease lodges. The fact of small particles of brass and copper having sometimes been found in the pitted holes, has given rise to the opinion that the corrosion is due to galvanic action. This supposition is, however, rendered improbable by the fact of the pitting being often more marked when no brass or copper is, or can be, present. The action of the acids can be prevented by introducing solid carbonate of lime or other substances having similar chemical properties, which will form with the acid a solid insoluble soap. This plan is, however, open to the objection that the heavy compounds are liable to settle upon the plates or tubes, and cause overheating.

9. When incrustation has once formed the safest plan for its removal is to chip it off carefully with suitable tools.

This is sometimes a most laborious and slow operation where the construction of the boiler is at all complicated and the scale is refractory. In such cases the chipping is by no means a simple process, and the ingenuity of the engineer is often taxed to devise suitable tools for acting effectively on inaccessible parts of the boiler. The chipping should always be carefully done, so as to injure the surface of the plates and rivet heads as little as possible. By rough and careless workmen the indentations made in the iron with the chisels and picks only serve as so many points for the firmer adhesion of the scale subsequently formed, and from which it is always more difficult to remove than from the unbroken surface of the plates. Any corrosive agent present in the water has also a better opportunity for attacking the iron when the surface is broken.

10. Perhaps the most objectionable method of removing

the incrustation, although frequently employed, is to crack it off by suddenly contracting or expanding the plates or the incrustation itself. The contraction is effected by suddenly letting into the boiler, after blowing off with the steam up, a volume of cold water, or opening wide the furnace doors, chimney damper, and entrances to the flues as soon as the fire is drawn. This is often found to bring the scale off in large fragments, or so to loosen it that it falls off during the subsequent working of the boiler, if it does not readily admit of being immediately hammered or wedged off. The consequences likely to arise from this reckless practice are too obvious to require special comment, suffice it to remark that it has directly caused the destruction of many a boiler, and indirectly the loss of many a life. It is an expedient too often resorted to by attendants who have an interest in showing the apparent efficacy of many worthless boiler incrustation remedies. Unscrupulous vendors of compositions and other alleged methods of removing incrustation have been known to bribe boiler attendants, who, in order to convince their employers of the alleged benefit arising from the use of the vaunted nostrum, are compelled to have recourse to the reckless measure in question.

The removal of scale by expansion is effected by cooling the boiler down, either suddenly or gradually, and allowing it to stand until quite cold, when steam superheated, or as hot as it can be procured, is let suddenly into the closed-up boiler. This has the effect of causing the incrustation to expand more rapidly than the underlying plates, when it breaks and falls off, or loosens its hold sufficiently to admit of being easily removed by manual labour. This expedient is only sometimes successful, but is always attended with a risk of starting the seams and joints, and so causing injury to the boiler. Its use cannot therefore be recommended. It has often been tried and failed, especially when the outside of the boiler is still warm, and the incrustation is covered with moisture, which prevents the sudden effect of the steam where it is required.

11. Attempts have been made at various times to prevent the formation of scale, and to remove it when already formed, by magnetism. The manner in which the electric current is induced in some of the so-called magnets that have been employed is by no means clear, and in some instances the production of any electric action is more than doubtful. And,

even supposing a current to be produced by the disturbance of the electric equilibrium, in the disengagement and discharging of the steam, the whole electric force, even when concentrated, is probably so small in amount under the unfavourable conditions found in a boiler, as to be of no practical importance.

Again, the manner of action of the electric current in preventing the deposit from forming or hardening is not known. Whether a vibration of the plates and tubes is caused, or whether they are made to expand and contract continuously, in such a manner as to loosen the scale and prevent its adherence, is by no means clear, and it is certain that any such actions could only prove detrimental to the boiler.

The employment of electricity as an anti-incrustative agent is almost abandoned at the present day, but we may shortly expect a revival of it in one form or another.

That this means of removing scale has been stated to be successful on what should be good authority there can be no doubt. But in more than one case it has been found that gold and not electricity was the agent to which the incrustation yielded. Any unscrupulous boiler attendant, by suddenly cooling the plates when emptying the boiler, can produce results which he can ascribe to the efficacy of any kind of anti-incrustator it may be to his interest to extol.

12. The simplest, and at the same time the most neglected, method of preventing and removing incrustation, is to allow the boiler to cool as gradually as possible, and to stand with the cold water in for a few days before emptying, which should be done frequently. By this means, which, however, in most cases requires the use of a spare boiler, the deposits are saved from being baked hard and fast to the plates, and the sulphate of lime already indurated has an opportunity of redissolving in the cold water, and on emptying a boiler with moderately bad water, a much greater amount of silt, mud or sludge will be found all over the inside below the water line than when the boiler is blown out with steam up.

Now, the difficulty of getting men to undertake the unpleasant job of wallowing amongst this wet mud in the attempt to brush it out of some kinds of boilers is the principal objection the advocates of this plan have to contend against. The labour can, however, be much shortened by washing out the sludge with a hose pipe when a head of water is available Boilers, by this simple method, and the use of a small quantity of soda, have been *relieved from the* evil of thick incrustation after the

failure of many expensive boiler compositions. Against this method it is sometimes urged that the bottom blow-out pipes become choked up unless the boiler contents are emptied while there is still a considerable pressure after the fires are drawn. This objection always proves a defect in the arrangement or attention to the blow-out apparatus rather than any defect involved in the principle recommended. When it is required to cool a boiler down rapidly, it will be found best to run in cold water at the same rate as the hot water is discharged. By this means the cooling is effected rapidly, but gradually and uniformly.

CHAPTER IX.

WEAR AND TEAR.

FROM the hour a boiler is set to work it is acted upon by destroying forces more or less severe and uncontrollable in their work of deterioration. These forces may be distinguished as chemical and mechanical. In most cases they operate independently, yet they are frequently found acting conjointly in bringing about the destruction of the boiler, which will be more or less rapid according to circumstances often difficult to detect or fix upon with certainty.

Corrosion, internal and external, but more especially the latter, is the malady that most boilers are liable to suffer from.

Internal corrosion presents itself in various forms, each having a character of its own, but only sometimes strongly marked. These are usually designated as—1, uniform corrosion or wasting; 2, pitting or honeycombing; and 3, grooving. The first mentioned is the effect of the chemical action of the feed water or substances introduced into the boiler; the second is also due to chemical agents, assisted, as held by many, by galvanic action; the third is due to chemical and mechanical action combined.

By uniform corrosion is meant that description of wasting of the plates or tubes, where the water corrodes them, in a more or less uniform and even manner, in patches of considerable extent, and where there is usually no well-defined line between the corroded part and the sound plate. Although seldom so uniform in its effects as ordinary rusting, this corrosion yet approaches it in its character and effects. The presence of this as well as of the other kinds of corrosion is generally not difficult to detect. Even when covered with a considerable thickness of incrustation its presence is often revealed on emptying the boiler by the "*bleeding*," or red streaks, where the scale is cracked. But in some cases, even where the plates are free from *incrustation*, uniform corrosion, in consequence of

its even surface and the absence of any well-defined limit to its extent, may readily escape detection. Often, when actually discovered to exist, the depth to which it has penetrated can only be ascertained by drilling holes through the plate and measuring the amount of material remaining. With lap joints the thickness remaining at the edge of the plate and round the rivet heads may serve as a guide to the amount of wasting; but this may prove treacherous, since the adjacent plates may both be corroded to an equal extent along with the rivet heads, which will give the edge of the plate the appearance of having the original thickness.

One of the most remarkable circumstances in connection with all kinds of corrosion is the apparently capricious manner in which it makes its appearance. For example, in two boilers alike in every respect, fed with the same water, and subject to the same treatment, one may be found attacked at the front end and at mid-height, whilst the other may be affected only on the bottom at the back end. In such cases there can be little doubt that the difference in the quality of the plates for resisting the corrosion has much to do with the apparent caprice of the acids in the water. The water from some wells and mines, and from certain canals and streams, attacks the plates violently only at the water line, whilst throughout the rest of the boiler the plates are comparatively or absolutely unharmed. In some instances this is very marked, the injury done to horizontal boilers being confined to a belt of about 6 inches or 8 inches at the water level, and in long vertical boilers to a belt of about 24 inches, according to the range of the water level. The boilers in some districts are attacked by surface and well water only on the bottom, whilst in neighbouring districts the tubes are attacked more than the shell, or *vice versâ*. In one case the corrosion is chiefly confined to the bottom of the furnace tube, in another it is limited to the narrow water spaces at each side of the tubes in Lancashire and similar kinds of boilers. The water in some localities, whilst but slightly acting upon the body of the plates, attacks the rivet heads or edges of the plates and angle irons. Sometimes it happens that it is mainly the transverse seam rivet heads and plate edges that are attacked, sometimes the longitudinal seams; out of 100 rivets 10 may be seriously affected whilst the rest remain sound; or the outer courses of plates on the bottom are affected more than *the inner courses*. The stays are often far more rapidly wasted *than the plates*. A screwed stay will be violently attacked at

the thread whilst the unbroken or turned surface will escape. In fact, it is almost impossible to conceive any vagary the acid in the water could commit, examples of which are not to be met with. This apparently capricious action of the corrosive agents is to be ascribed to their gravity, to their concentration in certain parts of the boiler, to their action being increased where the temperature of the plates is highest or lowest, to the circulation of the water, to the nature of the iron, and to other more hidden causes.

With the feed water from one supply only, corrosion is found more often under an incrustation of sulphate of lime than under one consisting chiefly of carbonate of lime. In many boilers fed with water containing the former salt a coating of oxide of iron of a black colour may be found adhering to the detached scale, which as often as it re-forms and is broken off brings with it a fresh film of oxide.

Another peculiarity worthy of notice is the different manner in which the plates and rivet heads behave with different kinds of waters after the wasting has been going on for some time. In most cases the corroded iron is readily removed, if it does not come off without means being taken to detach it. But cases are to be met with where the corroded iron adheres tenaciously to the sound plate beneath. In such cases considerable force is required to remove it, and the presence of the corrosion is not suspected until the hammer or pick is forcibly applied.

It is the opinion of many that the presence of a small proportion of carbon in steel will preserve it in a great measure from the wasting effect of bad feed waters. No doubt it does so almost totally with some waters, but with others it appears to have the opposite effect.

Unlike ordinary internal corrosion, the extent of the effects of pitting and honeycombing are well marked by the sharply defined edges they present. The term honeycombing is most aptly applied when the plates are indented by very small holes close together. Pitting may be defined as confluent honeycombing, and is found in holes and patches varying from $\frac{1}{2}$ inch to 12 inches diameter, and assumes most irregular forms. The depth of the cavities varies from $\frac{1}{32}''$ to $\frac{1}{4}$ inch or more. This form of corrosion is certainly most capricious in its attacks. It may be found on every plate of a boiler in contact with the water, and sometimes in the steam spaces and domes ; or it may be found only on a single plate either above or below the water line ; *whilst the remainder* bear no traces of corrosion whatever.

Boilers fed from the same water main and worked under similar conditions are sometimes found pitted in strangely different manners. Out of half a dozen boilers made of plates of the same brand, and worked side by side, one may be found so severely pitted as to require the renewal of one or more plates, whilst the other five boilers remain not at all or scarcely affected.

The mysterious manner in which pitting so often occurs, and its peculiar character, have not yet been altogether satisfactorily explained. It was once commonly ascribed to voltaic action between the iron plates and the brass tubes when found in locomotive boilers, but this theory was found to break down when the same pitting was found in similar boilers with iron tubes, and having neither copper nor brass near the portion affected. It was then advanced that the voltaic action took place between the different qualities of the scraps composing the plates, which are understood to exhibit different electric conditions, the electro-positive metal of the battery acting on the chemical solutions in the water, and becoming decomposed. Then it was advanced by the supporters of this theory that pitting would not occur with an electro-homogeneous metal such as cast steel, since the third element would be wanting. But cast-steel plates have been found to suffer from pitting as much as iron, and even more with some waters; yet with other waters which severely attack wrought iron steel is found not to suffer in the least. The pitting of cast steel either proves that it is not the electro-homogeneous metal it was supposed to be, or that the pitting of boiler plates is not due to galvanic action, unless the electro-negative element, as well as the exciting agent, be present in the water. The sharpness of the edges of the cavities is stated to be increased as the intensity of the voltaic action increases.

After all that has been said and written on this question it would seem that the phenomenon of pitting can in most cases be just as satisfactorily explained as being the result of simple chemical action without the aid of galvanism.

The concentrated acids of the water will attack the most susceptible portions of the plates. Whether the plates in the steam space are attacked or not will depend upon the nature of the acids, whether they are volatile or not, or whether the liquid acid is carried into the steam space by priming.

The wasting of the inside of locomotive firebox shell plates round the copper stays is generally set down to voltaic action. In what degree this may be the actual cause cannot readily be deter-

mined, but there can be no doubt that the wasting of the plates round the holes is in great measure due to the injury sustained in punching, which renders the iron more susceptible to the action of the water. Drilling instead of punching the stay holes has been attended in some cases with good results, enabling the plate to hold out much longer against the wasting effect of the water.

The rapid local wasting of locomotive firebox stays where they pass through copper plates, which often occurs when certain kinds of feed water are used, is perhaps the most conclusive evidence of the presence of galvanic action. $\frac{7}{8}$ inch bolts become reduced in a few years to half their original diameter inside the hole, whilst the thread in the copper plate remains perfect, and the bolt is not affected by corrosion about an inch from the copper plate. The wasting often commences first at the stays, near the firebox crown, where it is probably induced by the bending action due to the expansion of the plates, which is most severely felt at this part.

As to the means to be employed for preventing internal corrosion, the surest is obviously to abandon the use of water which has a corrosive effect upon the plates. At mines where the bad feed water is drawn from the ground it can sometimes be replaced by surface water more free from acids, and in cities, when the well water is found to injure the boiler, it can generally be replaced by the town supply of a better quality. There are, however, cases where the expense of using towns' water is so great that it is found more economical to employ corrosive well water, and lay down a new boiler every five or six years. This practice is however attended with great risk, on account of the temptation to use the corroded boiler to the last minute of safety.

When the water is found to affect the plates only in particular places, as at the water level, it is well, on the score of economy, to introduce thicker plates in such places, and to arrange them so that the seams of rivets, which are the weakest portion, do not come within the region attacked by the water. There exists great prejudice against introducing plates of different strength into a new boiler shell, in consequence of the non-uniformity of strain throughout the structure it involves, which in many cases is already more than desirable. But the question arises, is there any greater disadvantage in having the non-uniformity of strength at the beginning than at the middle of the life of the boiler, since the irregularity in

strength must, under the circumstances we are considering, necessarily occur at one time or another? There appears to be no sound reason for hastening the time for repairs, by making the strength uniform at first, when it is known that it cannot long continue so.

When there is no choice of feed water, the simplest method of preventing the corrosion caused by the majority of waters is to neutralise the acidity by treatment with some alkaline substance, either prior or subsequent to the introduction of the water into the boiler. This is best done by using soda, soda ash, or caustic soda, which should be dissolved and constantly introduced with the feed water, rather than in doses at long intervals. The quantity required will vary according to the strength and quantity of the acids in the water. It must however be remarked that when strong saline solutions are formed in the boiler, as in using salt water, the introduction of soda will be found to be an evil, and the only remedy in this case is to keep down the strength of the solution by frequent blowing off from bottom and surface. The methods of filtration and surface condensation have been found to answer well. When comparatively pure water, such as is obtained by surface condensation or from the water supply of some towns, is found to act injuriously on the plates, the corrosion may be prevented by allowing an amount of impure water to enter the boiler sufficient to deposit a thin layer of scale, which will protect the plates against the action of the more pure water.

Grooving, channelling, or furrowing, as it is variously called, is found of two different kinds, which, however, do not always present such distinctly marked characters as to precisely indicate the different causes of their formation. One kind is caused entirely by the straining and fretting of the iron, where a considerable change in the direction of the strain takes place. Where it is not aided by the corrosive action of the water, it may penetrate deeply into the plate or angle iron, without being more than $\frac{1}{16}$ inch in width at the surface. Sometimes this grooving is so fine as to appear more like a fracture, and is very difficult of detection. Any acidity in the water appears to widen the grooving, by attacking the surface laid bare. It is most commonly found in stationary boilers of the Cornish and Lancashire types on the flat end plates round the edge of the angle iron over the tube crown, and more frequently at the front end than at the back. It is usually deepest near the

centre of the crown, and extends on either side for a length of from 6 to 24 inches, and gradually disappears. Sometimes the grooving selects the root of the angle iron or flange of the tube plate instead of the end plate. The choice will depend upon the relative power of resistance of the parts joined. These angle irons are usually about $\frac{1}{2}$ inch thick; and when the plate does not exceed $\frac{9}{16}$ inch in thickness, it is almost invariably chosen; but when the plate is $\frac{11}{16}$ or $\frac{3}{4}$ inch thick, the grooving is often found in the angle-iron root. In like manner, when the furnace-tube plate is flanged, being the weaker, it is selected, the grooving taking place in the corner of the flange rather than in the end plate.

This grooving is caused by the too rigid staying of the ends by gussets or other stays, and by the difference between the expansion of the tube crown and boiler shell. As far as the bridge only the furnace crown is heated by the fuel and gases, the bottom being kept comparatively cool by the entering current of air. When the flue tube beyond the bridge is clean, the whole circumference is exposed to the radiation and contact of hot gases; but even in this condition it is improbable that the bottom receives anything like the same amount of heat by radiation that the top receives by contact with the flame which clings to the upper side. After the boiler has been at work a short time the bottom of the flue is maintained at a comparatively low temperature by the dirt that accumulates upon it. We may therefore consider the flue crown, under ordinary working conditions, as being much hotter than the bottom, and the greater expansion must cause a correspondingly greater strain at that part of the end plates to which the crown is attached.

This longitudinal expansion is accommodated in part by the springing of the end plates and in part by the arching of the tube. That this arching takes place has been proved by actual test, the tube of a 30-feet long boiler having been found to rise fully $\frac{3}{8}$ inch near mid length on heating the water to the boiling point, and without forcing the fire. Such an elevation of the crown is too great to be accounted for by the circumferential expansion alone. Were the longitudinal expansion, which must take place very gradually, maintained at the same degree all the time the boiler is at work, it would not account for the grooving; but every time the fire-door is opened the rush of cold air against the hot plates must cause *them to contract* suddenly, and to this rapid contraction,

repeatedly taking place, must be ascribed the action which causes the fretting of the rigid end plates or angle irons, as the case may be, which results in grooving round the end attachment of the furnace crown. The means for preventing it is simple. We have only to lessen the rigidity of the end plate, so as not to confine the bending action to one line. This may be done by allowing a sufficient distance between the tube and the end-plate stays for the plate to spring freely. Nine inches is found sufficient with $\frac{1}{2}$ or $\frac{5}{8}$ inch plates. The use of "Adamson" or "Bowling" hoops, which allow the tube to expand freely and reduce the strain upon the end plates, will prevent grooving to a great extent.

The grooving is not always confined to the crown, being frequently met with on the front end plates of Lancashire boilers between the tubes, when these are very close together and secured to the ends by "spectacle" pieces, the water space being too small to admit of using angle irons. This grooving at the "spectacle" plate is probably in some measure due to the variations in the temperature of the two tubes not taking place simultaneously, which is especially the case with alternate firing. The only cure for this grooving at the middle water space is the removal of the "spectacle" piece and tapering down the ends of the tubes, to give increased space to allow the end to spring.

It is but seldom that grooving is met with at the water spaces between the tubes and shells of Lancashire and other double furnace-tube boilers. A few instances of this have, however, occurred. Such cases are liable to be overlooked in consequence of the inaccessibility of their position. Their presence is more difficult to account for than the other cases; but this side grooving is found in conjunction with a low fire-grate, very thick end plate, and cramped side water spaces. Cases of grooving beneath the tube are extremely rare.

There can be no doubt that introducing the feed water at a high temperature, near the level of the tube crown, and thereby improving the circulation and decreasing the difference in temperature above and below, tends to lessen the end grooving. "Galloway" boilers are not found to groove so much as "Lancashire" boilers, similarly stayed, probably owing to the better circulation of the water in the former.

The trouble from grooving and leaking caused by the too *rigid staying* of the ends of internally fired boilers has, in *many cases*, led to their abandonment. In order to avoid the

grooving over the tubes of Cornish and Lancashire boilers, many makers rashly dispense with gusset and longitudinal stays, and substitute inefficient stiffening ribs of angle or T irons, the result being dangerous fractures through the line of rivet holes, or at the root of the angle iron securing the end plate to the shell.

Other examples of grooving, caused by the upsetting action near the parts affected, may be mentioned. The domes of locomotive boilers are sometimes found grooved internally, in a line opposite the edge of the angle iron attaching it to the shell. This is caused by the great strain thrown upon the angle iron, in consequence of the large quantity of the shell it is still too often the fashion to cut out for the dome hole.

The shells of vertical boilers, with internal furnaces, are liable to internal grooving round the upper edge of the foundation ring, between the shell and tube, when the ring is not made of sufficient depth to resist the upsetting action caused by a severe downward pressure on the furnace crown.

The curved bottoms of haystack and wagon boilers under pressure have also a tendency to upset the angle iron attaching the bottom to the shell, which results in internal grooving at the sides of the shell along the edge of the angle iron.

Internal grooving is frequently found round the edge of the angle iron on the flat ends of plain cylindrical boilers. In such cases it is caused by the insufficient stiffness in the end plate allowing an alternate bulging and flattening action to take place under varying degrees of pressure, which strains and frets the plates at the line of attachment. The furrowing produced by this action is often found at the root of the angle iron, instead of in the plate or in the corner of the flange when the plate is bent. Grooving from this same action was a common cause of the failure of the old flat-botttomed and sided wagon and haystack boilers. It is also met with round the flat and cambered crowns of vertical boilers, of large domes, and of the vertical tube in Rastrick boilers.

It is thus seen that grooving may be due to want of stiffness, as well as to an excess of stiffness under different conditions.

The other kind of grooving alluded to at page 192 is usually found running parallel with and close to the edge of the plates in lap joints. It is much wider at the surface of the plate than the first-mentioned kind of grooving, and has often the appearance of having been gouged out. It is caused mainly by the *corrosive action of the* water, but is induced by the buck-

ling and fretting of the plate at the line where it is found. This buckling is due to the oblique action of the circumferential and longitudinal strains at the joints, either from the steam pressure or from unequal expansion and contraction. At the longitudinal lap joints the buckling is also due in some measure to the cross-bending action produced by the internal pressure tending to force the plates into a perfectly cylindrical form.

In stationary boilers, which are but seldom worked at more than 80 lbs. pressure, internal grooving at the longitudinal lap joints is not often met with, unless the boiler barrel deviates 2 inches or more from the truly cylindrical form, yet it is sometimes found at the longitudinal seams of old boilers where they run in a continuous line from end to end. At the transverse lap joints of long Cornish and Lancashire boilers internal grooving frequently occurs, but not of a very decided character. Its presence can generally be traced to the difference in expansion between the bottom and top of the shell, or between the flue tubes and the shell bottom. It is most marked in boilers where the circulation is bad, which is especially the case when the cold feed water is introduced at the bottom.

In locomotive boilers working at 140 lbs. pressure or more, and where the plates are thick in proportion to the diameter, internal grooving at the seams is most frequently met with. It occurs at the longitudinal lap joints below the water level, principally at mid length of the barrel or near the smoke-box end, at the ring seams all along the boiler, and very often in the plate opposite the edge of the outside angle iron attaching the barrel to the smoke-box tube plate. It is most marked at the bottom of the barrel, and diminishes gradually, until it dies away near the centre line.

Transverse furrowing also occurs in the body of the plates when they are too rigidly attached to the frame by plate stays, secured by angle irons to the boiler shell. It is found opposite to the edge of the plate or angle iron.

As this description of grooving always occurs at the edge of a plate, or opposite the edge of an angle iron in a line where the direction of the strain caused by the steam pressure or by expansion and contraction is liable to be changed, it suggests the probability of its being caused by mechanical action, which, producing a bending or springing of the plate along the line where it occurs, breaks off the coating of incrustation or the outside scale of the plate itself, thus continuously exposing a

fresh surface for the chemical action of the water. Moreover, as the longitudinal grooving only rarely takes place above the water line, and as it is found to occur with one kind of water and not with another, it may reasonably be concluded that it is chiefly due to chemical action, although induced in the first place by mechanical action.

The buckling action at the longitudinal seams being caused by the unequal distribution of strain at the overlap, or by the tendency of the barrel to assume a perfectly circular form under pressure (which form is necessarily departed from at the lap joint), may be prevented by doing away with the lap joint, and using welded joints or butt joints with double butt strips. Or, retaining the lap, the result of the chemical action may be prevented by keeping the longitudinal seams above the water level, which has been done by making the courses of plate in one length. The evil of longitudinal furrowing has been overcome by either of the above methods. In some cases, however, where welding has been tried, it has been found that the plates are rapidly pitted at the weld; and this plan had, in consequence, to be abandoned, unless the joints were kept above the water level.

At the transverse lap joints the buckling is caused by the boiler being too rigidly tied to the engine frame, and not being allowed to expand and contract freely, or, as it is sometimes called, to breathe freely. It is also aggravated by the vicious practice of attaching the drag apparatus directly to the boiler. Another cause of the buckling at the shell bottom is the strain thrown upon the bottom plates by the greater expansion of the tubes compared with the shell.

There can be little doubt that internal grooving is often induced by excessive caulking, which, by destroying the skin of the iron, exposes a surface for the easier attack of the corrosive agents in the water. On this account many engineers discountenance the practice of caulking the plates on the inside.

External corrosion is a more frequent and more subtle destructive agent with stationary boilers than any kind of internal corrosion. This probably arises from the fact that its presence is less suspected, and is often less easily detected in consequence of the inaccessibility of the plates. It is therefore left to do its work of destruction without any attempt being made to arrest its progress. It is found either as uniform corrosion in large and small patches, or as grooving.

The most *frequent sources* of external corrosion are exposure

to the weather, leakage from joints of plates and fittings, dripping from mountings, moisture rising from the ground near the boiler, either from the damp nature of the ground or from the want of waste pipes to carry off the water from the blow-off tap, water gauges, &c., and from the careless practice of damping the ashes close to the boiler.

When leakage takes place at the boiler crown to any great extent, the whole circumference of the shell being below, is liable to suffer wasting from it. A slight leakage from a bad joint may be sufficient to cause a severe local grooving at the seam or flange, as it often goes on for a length of time unperceived and unsuspected, especially when the shell is covered by brickwork or other material to prevent the radiation of heat. Some of the compositions used for covering boilers, however, become soft, and at once betray any leakage that may be going on beneath. To prevent leakage at the joints of the mountings, they should always be riveted and caulked to the curved plates, and never attached by bolts or studs. The greatest difficulty in making a good joint on a curved surface by the usual means of studs or bolts and nuts is found at the blow-out pipe attachment of ordinary factory boilers, where the joint has to bear the reckless twisting and straining from the use of a long lever every time the blow-out tap is turned. In nearly all cases where the blow-out attachment is not riveted to the shell, the plate becomes rapidly wasted round the bolted flange.

To the injudicious practice, which still largely prevails, of building boilers in with a mass of brickwork, the greatest amount of deterioration from external corrosion must be attributed. This evil acts directly in keeping any water that may find its way to the boiler in contact with the plates, and also indirectly in preventing the detection of any wasting that may be going on.

The most glaring example of this kind is to be found in placing internally fired boilers on a wide midfeather or supporting wall extending along the middle of the shell nearly from end to end. Any water from leakage or other source trickling down the shell naturally finds its way to the bottom, and when it is held here in contact with the plates a rapid oxidation takes place. The wasting is often promoted by the presence of damp mortar, which should never be allowed to touch the plates, and by corrosive agents in the products of combustion which sweep past. These midfeathers are sometimes as much as 2 feet wide, and very commonly 14 or 18 inches. In

such cases it is impossible to tell by ordinary examination in passing along the flue the condition of the plates resting on the brickwork. It frequently happens that to all appearance no damp is present, and the plates near the edge of the midfeather are in good order, yet on removing the brickwork the plates for a width of 6 or 8 inches at the centre all along the boiler are found eaten nearly through.

With boilers of 4 feet diameter and upwards midfeathers should not be used. The boilers are much better placed on side walls with a total bearing surface of from ¾ inch to 1 inch per foot of diameter. In very small boilers where side walls are not admissible the bearing of the midfeather need never exceed 3 or 4 inches in width; and a loose brick should be left here and there, or at least at every ring seam, for removal to facilitate examination. When there is any dampness in the ground beneath the boiler, it invariably travels up the brickwork and attacks the plates. Where the dampness cannot be removed, it is advisable to cut off the contact between the plates and the brickwork, by supporting the boiler on cast-iron saddles and a longitudinal cast-iron carrier, which need not exceed one inch in width, and can be taken the whole length required.

The front cross walls of internally fired boilers are often made of excessive thickness, being sometimes as much as 3 feet, and built round and made to conceal the blow-out pipe and attachment, which are thus rigidly built up and rendered liable to break. As the boiler is supposed to rest upon the midfeather or side walls, the front cross wall, or at least the top of it in contact with the plates, need scarcely ever be more than 4½ inches thick, and it should always be built round behind the blow-out pipe attachment, which is thus placed in an open recess in the wall accessible for inspection, and not rendered so liable to fracture. Even with a 4½-inch wall there is still a risk of corrosion if the ground be damp, or the water from the blow-out tap be not led away by a waste pipe, but is allowed to splash back against the front cross wall, as is too often the case.

When the ground is of so damp a nature, from situation or formation, that the moisture from it passes up the front cross wall, the only means of saving the boiler is to interpose loose plates between the wall and the shell, which become corroded instead of the boiler plates.

It is a common practice to allow the front end angle iron of Cornish and *Lancashire* boilers to rest on this front cross wall.

This has the disadvantage of concealing any leakage or defects at the angle iron. The front wall is therefore better kept clear of the angle iron, that is, the front end plate should project 4 or 5 inches beyond the wall. The front end plates of Lancashire and similar boilers are very often severely corroded externally at the floor line by the water that always finds its way here from one source or another. The boiler should, therefore, always be arranged with the front end plate clear above the floor. In order that this may not interfere too much with the facility of firing, the floor may often with advantage be inclined or let down to suit.

The practice of slacking the hot ashes against the front end plate is a very common source of corrosion above the floor line. Where there is good reason for adopting this practice it will be advisable to protect the front plate by a suitable sheet iron guard.

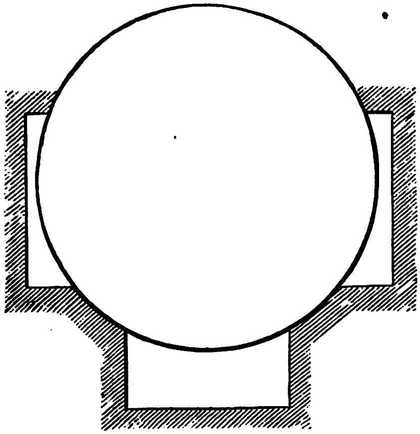
The side wall bearings on which internally fired boilers are now usually supported, and to some extent externally fired boilers also, are frequently made of excessive width, from 15 to 20 inches being not uncommon. Now, 3 or 4 inches of bearing surface to each wall is quite sufficient for ordinary-sized boilers, or as a rule from $\frac{3}{4}''$ to $1''$ of total bearing surface per foot diameter of boiler.

In order to allow the escape from the plates of any water flowing down the shell sides, the side wall bearings should be made of fire lumps, as shown in fig. 22, rather than made after the old fashion, as in fig. 21. This last plan leaves the water no choice but to cling to the plates in finding its lowest level, and often leads to serious corrosion. Care should always be taken to keep the longitudinal seams well clear of the seating. Another indirect source of corrosion sometimes met with is the extremely narrow space allowed at the top of the side flues of many boilers. When this space is only an inch or two wide, it cannot well be cleaned. The soot accumulates and becomes hard, and then retains moisture in contact with the plates, which sooner or later may cause serious corrosion all along the boiler where it is seldom suspected.

The back and front ends of externally fired boilers are not unfrequently set in a mass of brickwork, which is apt to keep moisture in contact with the plates. No reason for this practice can be given. It is usually done through ignorance on the part of the builder or draftsman, or from want of constructive skill on the part of the brick-setter. When these boilers are

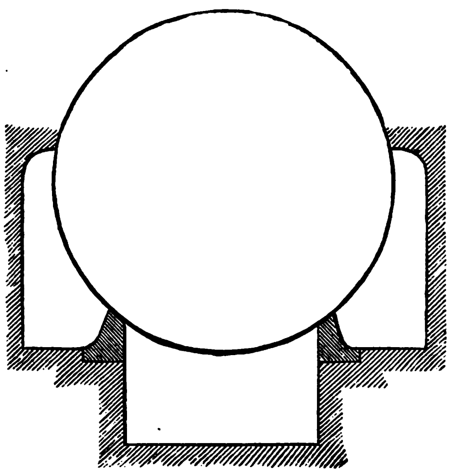
suspended from side brackets with a flash-flue arrangement, it is not unusual to find a belting of brickwork 18 or 24 inches

Fig. 21.



thick, and even more, in contact with the plates. This arrangement is obviously liable to harbour a quantity of moisture,

Fig. 22.



whose damaging effects on the plates are placed beyond detection unless the brickwork is periodically removed.

The plan of carrying a thick cross wall over the front end of internally fired boilers, and also of covering the front end plate with brickwork to prevent radiation, is apt to lead to wasting at these parts, and should not be adopted.

Vertical furnace boilers are sometimes found built into walls, and seated on a mass of brickwork, which retain the moisture and lead to a rapid wasting of the plates. The practice of lining with fire bricks the internal flue tubes of upright furnace boilers, has been found destructive to the plates by keeping the water in contact with them. When it is necessary to apply this brick lining, in order to protect the plates from overheating where the tube passes through the steam space, or from burning where the flame impinges, it is advisable not to build the brickwork in contact with the tube, but to preserve an annular space to allow the water from leakage and other sources to run down and escape.

Corrosion is met with in the furnace tubes of internally fired boilers, beneath the heavy bridge of brickwork, so often needlessly built upon the tube bottom. These bridges are as well supported, and more easily removed, when built upon metal bridge carriers.

Leakage at the riveted joints in any part of a boiler may be due to bad workmanship. When caulking and the insertion of new rivets will not cure the leakage, the holes should be carefully rimered out afresh, and larger rivets put in; at the same time the edges of the plates may be dressed and recaulked. Too much lap is very often the cause of the difficulty in making a tight joint, especially at the furnace plates. New boilers often leak at the seams when set to work, after having been tested and found tight at the maker's. This may be due to rough usage in removing the boiler and fixing it, or to the expansion of the plates in actual work being different from that produced by the test. A difference in the nature of the feed water has sometimes a remarkable effect in making boilers leak at the riveted joints below the water line. A boiler may be quite tight with one kind of water, and yet leak badly with another kind. When this is the case, it is generally found that a comparatively pure water has been changed for brackish water, or one containing much carbonate of lime, the use of which is attended with a higher temperature of the furnace and flue plates, and consequently a greater local expansion. Leakage is

often produced at the furnace and flue seams of many boilers by getting up steam too quickly. The leakage in this case is chiefly due to the unequal expansion of the material, one part of the boiler being hot whilst the rest remains cool. Leakage from this cause is most common in boilers having a bad circulation.

Leakage at the ring seams, especially of externally fired boilers, is very often caused by delivering the cold feed water right on to the hot plates; sometimes the feed pipe delivers right on to a seam. It has more than once been questioned by those who will not be advised to introduce the feed in a proper manner, whether the introduction of the cold feed water downwards through a vertical pipe, the end of which is some 24 inches above the plates, can have any effect in suddenly contracting them. This, of course, will depend upon the force with which the water is injected. In cases where a range of half a dozen or more boilers is supplied by a donkey pump sufficient to feed all at once, there can be little doubt that when only one boiler is being fed at a time the water will be injected with sufficient force to reach the plates even more than 24 inches below the end of the pipe, without having much heat imparted to it in its downward course through the hot water in the boiler. In such cases the fracture of the plates beneath the pipe is not an unusual occurrence.

One of the most common causes of leakage all along the under side of boilers, and also at the tube plates, is the reckless practice of emptying the boiler while still hot, and filling it with cold water, at the same time leaving the damper wide open and removing the flue doors, in order to cool the boiler rapidly for cleaning. The sudden contraction of the furnace and flue plates thus produced has been the ruin of hundreds of boilers. The equal contraction of the bottom plates of externally fired boilers is sometimes resisted by the plate edges or suspending brackets butting against the solid masonry: fracture in these cases is the common result.

Internally fired tubular boilers, without external flues, and usually made with a cluster of small tubes at the back end, are invariably found to corrode and groove externally along the shell bottom at the ring seams, in consequence of the leakage caused by the unequal expansion of the top and bottom of the boiler, and also of the flue tubes and the shell. This inequality is due in great measure to defective circulation, and to the unavoidable difference in temperature between the internal flues

and shell crown on the one hand and the shell bottom on the other. The best and perhaps only means of preventing this leaking and grooving is to apply external flues leading the gases first under the boiler bottom before entering the side flues, and to allow some spring in the end plate.

Boilers of the locomotive class are without external flues, and yet do not usually leak at the bottom when the shell is free to expand. The reason of this is that the circulation is favoured by the construction of this class of boiler, which admits of the tubes being brought near the shell bottom; at the same time the water at the lowest part of the boiler—the firebox—is heated. Any severe leakage at the transverse seams of locomotive boilers can generally be traced to the interference of the end contraction and expansion by some of the barbarous styles of staying the boiler to the frames, which, unfortunately, to some extent still exist.

The strain along the bottom of long Cornish and Lancashire boilers produced by the expansion of the bottom compared with the top, and the still greater expansion of the through tubes, sometimes results in fracture at the ring seams, and very frequently leads to leakage, which has the effect of grooving the bottom plates in a characteristic manner at the edges of the transverse seams. The rapidity with which this grooving occurs, and other evidences of the intensity of the chemical action, can only be accounted for by the presence of some strong acid, and there can be little doubt that the sulphurous and other acids from the coal are the principal elements of destruction. Water is considered capable of absorbing 30 times its volume of sulphurous acid; and when this acid is given off abundantly by coals containing pyrites, the rapid grooving at the ring seams is not difficult to account for when the boiler leaks at the bottom. The unequal expansion and contraction which produce the leakage can nearly always be traced to defective cirulation, either from the cold feed water being introduced at the bottom, or else, in the case of Lancashire boilers, from the side and middle water spaces being too narrow. These defects can be remedied by heating the feed water; by introducing it just below the water level, where it should be well distributed; and by improving the circulation by the addition of vertical water tubes when the side and middle water spaces are too cramped.

The riveted joints in the furnace tubes of internally fired tubular boilers are liable to leak, and cause corrosion and grooving on the fire-side of the tubes when these are bound to

each other or to the shell by plate-stays, and are thus prevented from breathing freely. These stays are needlessly introduced by some makers to support the tubes, and are sometimes rigidly attached to strengthening angle irons round them. They are a source of much trouble by causing the tubes and shells to leak, and they frequently lead to fractures in the plates.

Combustion-chambers and tube-plates are often corroded by the leakage from the small tubes. In many boilers of the locomotive class the tubes are caused to leak by the rigid manner in which the tube-plate at the fire end is fixed from the staying of the fire-box crown. The want of freedom in the tube-plate to expand and contract causes the tube-holes to become oval, after which it is almost impossible to prevent leakage. The distortion of the tube-holes is sometimes caused by the excessive pressure concentrated upon the tube-plate by the girder-stays that support the furnace or combustion-chamber crown. These girder-stays should be attached by sling-stays to the shell-crown. Too great rigidity may be avoided by slightly slanting the sling-stays. Tubes are often caused to leak by attempting to get up the steam too quickly, or by blowing out the boiler while the plates and tubes are still at a high temperature.

Wasting from severe leakage is very common at the bottom corners of the fire-boxes in boilers of the locomotive class. This is often produced by the difficulty found in making a good joint at the sharp corners, which are generally made of a radius too small to get a rivet through at the corner. In order to avoid the defect in question some makers double-rivet the fire-box bottom either all along or merely at the corners; others make the corner of the inside to a radius large enough to get rivets through, and so draw the plate to the ring all round.

External corrosion from leakage takes place round manholes and mudholes without mouth-pieces from the difficulty found in keeping the joints tight, and at washout-plugs and mud-plugs from defective threads. These threads, when formed merely on the plate, are soon worn off by screwing and unscrewing the plug, and by the iron rods passed through the holes for the purpose of cleaning. These holes should, therefore, be arranged with mouth-pieces having a male instead of a female screw.

The various kinds of fractures to be met with may be divided into two classes, viz.: 1, those caused by want of freedom in the plates to expand and contract, by the unequal expansion of the material in *different* parts of the boiler, and by too sudden

expansion and contraction; 2, those caused by weakness and inability of the material to bear the steam pressure, and which may be due to bad workmanship, originally bad material, or deterioration of material originally good, malconstruction, injudicious repairs, corrosion, overheating, and fatigue arising from long exposure to variations of pressure.

There are probably no fractures of such frequent occurrence as those found at the lap joints of the furnace-plates in externally fired boilers. They are most common at the transverse seams between the end of the boiler and the bridge, yet are frequently met with at the longitudinal seams, and also at the segmental seams at the hemispherical ends, where these are exposed to the action of the fire. The fractures are most common from the holes to the edge of the plate in the outside lap, where they may not be actually dangerous at first, but are very troublesome and cause much annoyance and expense through the delay and repairs they necessitate. They are usually scarcely visible at first, but in time become more open, and give rise to leakage, which is generally the means of drawing attention to their presence. In time these lap-edge fractures often pass through the rivet holes into the body of the plate, where they are likely to prove very dangerous if their progress be not arrested by drilling holes and placing second rivets in their path, which generally proves effective. When the fractures run in a line through the rivet holes, either at the longitudinal or transverse seams in the shell, they must be regarded as dangerous, and carefully watched. Plates of good quality will leak at the fractures, and give indication of danger where brittle plates would give way suddenly without warning. The liability to fracture in the furnaces of all boilers is greater with thick than with thin plates.

The lap-joints in the shells of furnace boilers opposite the furnace throat, and also the lap and T-iron butt joints in the furnace tubes of internally fired boilers, are liable to the same descriptions of fracture, but especially to those from the holes to edge of plate. These lap edge fractures are generally ascribed to the overheating caused by the impingement of the flame against the double thickness of plate at the lap. But it is clear that the greater heat at these parts would cause an increased expansion that would have the effect of compressing the material, instead of extending it, and thereby causing fracture. Against this theory it may be stated, that the seams over *the bridge* which are most exposed to the impingement of the

flame are very seldom found to fracture. The actual cause of fracture at these furnace-plate joints appears to be the sudden longitudinal and circumferential contraction on cooling every time a current of cold air strikes against the plates. If we consider the effect of the heat on the ring seams, it is evident that the greater the thickness of plate, the greater will be the elevation of temperature and tendency to expand at the joint. Regarding the double thickness of plates at the lap as an arch, whether concave or convex to the fire, the expansion will find full play in gradually increasing the height of the arch either upwards or downwards, as the case may be. The form of the expanded cylinder will of course be modified by the internal pressure. On the current of cold air coming in contact with the joint in its expanded state, the effect of the sudden reduction of temperature will be to throw a sudden tensile strain on the outside plate of the lap. This contraction is resisted by the inner plate, which still retains the form due to its higher temperature, and fracture from the rivet hole to the edge of the plate is the inevitable result if the ductility or elasticity of the iron be too severely taxed. After a certain amount of expansion and contraction even the very best plates become brittle, and fracture from the rivet holes to the edge of the plate. Fracture through the line of rivet holes at the transverse seams is caused by a longitudinal tensile strain acting in a somewhat similar manner. Fractures of both kinds at the longitudinal seams over the fire are also caused somewhat after the manner just described.

Many cases of fracture are met with which, on account of their protected position, cannot at first sight be accounted for by the cooling action we have just considered. Such, for instance, as the edge fractures in the longitudinal lap joints placed just above the fire-bars of some internally fired boilers. Since the fractures here are placed in the fire, they cannot have been caused by the air currents through the furnace door. Yet being just above the bars, the joints are liable to have a strong jet of cold air suddenly let in upon them when the hot fuel is removed on stirring or cleaning the fire, processes that must be repeatedly performed with any description of coal that yields much clinker.

Again, it would appear, at first sight, that the edge fractures that so frequently occur at the outside laps in the shells of some descriptions of furnace boilers, just opposite the furnace throat, are out of reach of any rush of cold air, being so far from the proper air-entrance by the furnace door. Yet it is

tolerably certain that these fractures occur on the removal, by accident or intention, of the brickwork near the place where the fractures occur, while the plates are still at a high temperature.

It has been attempted to explain the occurrence of these fractures by assuming that the intense heat and ebullition prevent the contact between the plate and the water. When the heat subsides, the water coming in contact with the overheated plate causes it suddenly to contract and fracture. This might certainly account for a fracture at the inner plate at the lap, but not in the outer plate. That fractures in the body of the plate occur in this manner is extremely probable.

The production of fractures after the manner described is aided by the tendency of furnace plates to become permanently shortened after oft-repeated heating and cooling.

As to the means for preventing these fractures, at the seams of riveting, in furnace boilers, the only method to ensure success is to guard the plates from both the heat and the cold air by a shield of brickwork, which, however, should be arranged so as not to harbour moisture against the plates.

With externally fired boilers the liability to fracture at the laps increases as the fire is approached to the boiler bottom. By lowering the height of the bars, which diminishes the intensity of the heat from radiation and at the same time allows the air to diffuse itself, a partial remedy can in most cases be effected. Attempts have been made to prevent the rush of cold air on opening the fire-door for stoking, by employing some self-acting apparatus to close the damper as the door is opened. This plan, however, interferes with the process of combustion, and is productive of smoke. Deflecting arches inside the fire-door, to direct the entering cold air on to the fire, instead of allowing it to rush straight at the plates, have also been tried with partial success. But the trouble of keeping these deflectors in repair leads to their disuse. The best and simplest means is to dispense with the transverse laps over the fire altogether, so as to do away with the excessive expansion and sudden contraction they give rise to from the thickness of iron their use involves. This can best be done by keeping the second ring seam behind the bridge by using a long plate over the fire. Before the air reaches this, it will be sufficiently heated not to act injuriously on the plate at the joint. This plate must be sufficiently wide to keep the longitudinal seams out of reach of the fire and cold air. The objections to this arrangement are the increased cost

involved in using such a large plate, and the long unbroken length of longitudinal seam it forms, which must be a source of weakness. This can, however, be partially compensated for by double riveting.

In order to prevent the liability to fracture in boilers with internal furnace tubes, the ring seams should be as few as possible, and made with "Adamson" flanges. The longitudinal seams should always be kept below the fire-bars.

Fractures of a dangerous nature, and which may be regarded as one of the commonest causes of explosion, take place at the ring seams of externally fired boilers, near mid-length, where no cold air can reach them. These fractures usually run through the rivet holes at the inner plate of the lap, and are brought about in boilers of moderate length by the sudden contraction of the plates consequent upon the cooling effect of having the feed delivered directly on to them, or of letting in cold water or air on the hot plates too soon after the boiler is emptied for cleaning. The quantity of brickwork in which these boilers are often imbedded, and the awkward manner in which they are sometimes supported by an unnecessary number of carrying brackets, must greatly interfere with their freedom to contract equally throughout their length, and in such cases even a cold current of air let in on the shell bottom, after the fire is drawn and the boiler is empty, is sufficient to produce a large transverse seam rip. In very long boilers the expansion of the bottom when at work would cause the shell to arch upwards as much as half an inch, or even more, at the ends, were this elevating tendency not resisted by the weight of water in the boiler. The arching is however sufficient to throw the whole weight of the boiler for a time on the middle supports, and after a length of service the contraction that takes place more or less in all plates subjected to alternate heating and cooling is sufficient to arch the boiler upwards in the middle when cold, thus lifting it clear of its middle supports, and throwing such a tensile strain on the bottom plates as to cause a transverse seam rip.

The expansion and its effects in all cases will of course be increased when the furnace and flue plates become partially overheated through being covered internally with a thick coating of incrustation, or when the water is very greasy, and contains carbonate of lime in considerable quantity.

The flat ends of shells and tubes are liable to fracture through the rivet holes, or through the corners of the angle irons or flanges securing them, *either for* want of sufficient stiffness or from

being too rigid, in the same manner that we accounted for internal end plates grooving.

The same causes that lead to grooving may also lead to fracture, directly or else indirectly, by weakening the plate sufficiently for the steam pressure to complete the destruction.

A common example of fracture from unequal expansion is found in the long vertical chimney boilers used in connection with forges and iron furnaces. These are like a Cornish boiler placed on end, the flue-tube being out of the centre to allow more space for cleaning, &c., leaving only about 6 inches between the tube and shell. The expansion of the tube is found in some cases to exceed that of the shell by fully half an inch. This necessarily throws an enormous strain on the end angle irons and rivets, resulting after a brief service in fracture through the rivet holes, angle iron, or plate round the edge of the angle iron. Were the bottom of the flue-tube in a Cornish boiler exposed to as much heat as the crown, many of these boilers as at present constructed could not be worked for the trouble and danger that would result from the rigidity of the end plate bottom.

The furnace crowns of small vertical boilers, when crowded with small tubes, are rendered too rigid and liable to fracture, as well as to groove, at the flange or angle iron securing the crown to the furnace. The rigidity is sometimes increased by dishing the crown plate, and the liability to fracture is consequently increased.

Many disastrous explosions have occurred, especially with externally fired boilers fracturing, immediately after repairs, at the longitudinal or transverse seams, through the lines of rivet holes where new plates have been joined to the old, or where the plates have been repaired with patches riveted or bolted on.

Many improbable causes have been assigned for these accidents; but the true solution of the mystery lies in the fact that the old plates are very often severely fractured by the clumsy manner in which the rivet heads are knocked off and the rivets forced out of the holes. Then, on putting on the new plates, the reckless use of the drift completes the mischief, and the joint is ready to part with a strain far below the working pressure of the boiler. Many of the numerous causes of fractures at the rivet holes already considered are assisted to an unknown extent by bad workmanship combined with brittle material. Nothing but the strictest supervision, and the employment of really skilful workmen, can overcome this evil.

But when boilers are constantly being bought at a price barely sufficient to pay for the plates of proper quality it would be hopeless to expect first-rate and trustworthy work.

In boilers of the locomotive class fractures often occur in the firebox tube plate, either at the roots of the flanges or through the material between the tubes, in consequence of want of freedom to expand and contract, or from sudden contraction. The liability to fracture at the flanges is greatly increased by making them with too sharp a bend.

Overheating may take place, and be confined to a very limited area, or it may extend over a large surface. Examples of fractures caused by overheating are most common in externally fired boilers. The causes which directly or indirectly lead to overheating are treated of in the chapter on "Explosions." When severe local overheating of any kind occurs in the body of a plate, the material softens, and bulging outwards from the pressure sometimes forms a pocket, which is eventually fractured by the pressure itself or by the contraction on the plate cooling down.

When fractures arise in a plate that has been so intensely heated as to drive the water off the surface, they may have been caused either by the pressure overcoming the tensional resistance of the softened plate, or by contraction on the water coming again in contact.

An effect of overheating but rarely met with is found in the fretting and partial fracturing of the outside surface of thick plates when exposed to an intense heat, as when a large body of flame becames concentrated and impinges on a limited surface. In such a case the outer surface of the plate is subject to much greater variations in temperature than the inner layers of the plate, and deteriorates more rapidly. It is also probable that the cracking of the outer face is in great measure due to the presence of corrosive gases given off by the burning fuel.

When a furnace plate is laminated, it is very liable to overheating on the outer surface in consequence of the increased resistance the want of solidity offers to the thermal conduction. The overheating causes the outer shell to bulge and form a blister, which sooner or later fractures either at the apex, when the thickness of the skin is uniform, or near the edge, when it is thinnest here, and offers the least resistance to breaking.

Fractures from overheating are very common between the stays in the flat *surfaces* of locomotive fireboxes. These are

caused solely by the softened plates bulging and yielding to the pressure.

Some of the plans that have been used for admitting air behind the bridge for smoke prevention have led to serious trouble from the alternate heating and cooling effect the air produces at various stages of the combustion, especially where the current of air has been allowed to impinge in considerable volume against the furnace plates.

CHAPTER X.

FACTOR OF SAFETY.

In seeking to determine the proper co-efficient or factor of safety to use for the testing and working pressures of a boiler, or in other words to decide what ratio these pressures should bear to the ultimate strength, to provide against defects arising out of wear and tear, as well as original defects of workmanship and material, we must ascertain the manner in which the boiler is strained and the power of the material to resist the strains under ordinary working conditions. In the case of a cylindrical boiler it is usually taken for granted that the fluid pressure and diameter on the one side, and the ultimate breaking strength of the plates or joints on the other side, are the only elements to be considered, and that the bursting strength as estimated from these data divided by proper factors of safety, usually 6 and 3, should give the working and testing pressures respectively. Now, in the first place, in many cases the steam pressure is not the greatest force the boiler has to withstand, and any increase of thickness in the plates, by its tendency to increase the strains arising from the sudden or unequal expansion and contraction, may be the means of weakening the boiler instead of strengthening it. The effect of these strains on the boiler should, therefore, always be considered in estimating its strength. In the second place, the method of fixing the factors of safety from the original ultimate tensile strength of the material alone can only be considered satisfactory if the strength, elasticity, and ductility of the material remain unchanged under all conditions of working and testing. We also require to know what strain the material will stand without producing such change of form or size as may be detrimental to the efficiency of the structure, and how the strength and character of the material is affected after long exposure to trying work.

If we submit a straight bar or plate of good wrought iron of regular section to a steady tensile strain, it will up to a certain point

be found to stretch uniformly about $\frac{1}{10000}$ part of its length for every ton per square inch of sectional area applied. If the bar returned fully and perfectly to its original length on the removal of the load, its elasticity would be said to be perfect. This theoretically perfect elasticity is not attainable, and it is probable that, if we had sufficiently accurate and delicate means of measuring the bar, it would be found to be permanently elongated by the smallest loads if permitted to act for a length of time; but for practical purposes the elasticity may be considered perfect up to loads of 3 or 4 tons per square inch, and with good wrought iron the permanent set is so slight for loads below the limit of 10 or 12 tons per square inch, or about one-half the breaking weight, as not to be sensibly felt in a boiler shell. Besides, with these small loads the permanent set will not be increased by any number of repeated applications of the same load, and it may therefore be considered as being consistent with perfect safety. But when the stress exceeds the above limit, it will be found that the set is increased by repeated applications of the same or even a less load, provided that time be allowed for it to act, and the limit of elasticity of the material is now said to have been exceeded. The limit of elasticity may then be defined as the greatest stress that can be applied without producing an increased set by repeated applications. The amount of elongation produced by a load exceeding the elastic limit will render the iron useless in most structures, and especially in a steam boiler, where the tightness of the joints will become destroyed even before such a strain can be reached. It is therefore evident that we must be guided directly by the elastic limit of the material, and not by its ultimate breaking strength, in deciding upon the stress we can safely subject a boiler to. For mild steel the elastic limit may be taken at 15 tons.

If we continue to stretch our bar by increasing the load until it tears asunder, and then restretch the broken pieces, we shall find that they will bear as great a load, or even greater than in the first instance, showing that the actual breaking strength is not reduced by a strain little short of that sufficient to produce fracture. But the character of the iron will have been changed, inasmuch as in the first instance the entire bar would be drawn out considerably before breaking, whereas in the following breakages the pieces will be found to break short off with comparatively little reduction of fractured area, exhibiting in consequence a more crystalline fracture. They will be less

able to stand a sudden strain, although their limit of elasticity will have been increased.

Now, it is extremely probable that the hardness which is induced by a severe dead weight acting for a short length of time may be produced by a very much less stress oft repeated and suddenly applied. This may explain why boiler plate, originally good and ductile, has been found after long service to become hard and brittle, more especially when it has been exposed to severe strains, as in the part of a shell having a large hole cut in for the dome, in some furnaces, or in locomotive boiler barrels connected rigidly to the frames. In addition to the comparatively constant and steady steam pressure, it must not be forgotten that many boiler shells are subject to severe shocks from the sudden opening and shutting of valves, as well as to severe tensile strains arising from the contraction caused by the sudden impingement of cold water or air against the hot plates.

The limit of elasticity of wrought iron is materially affected by the number of times the application of the load is repeated, and also by the difference between the constant load on the material and the increment of load that is applied, as well as by the length of time the constant and variable stresses act. From the results of carefully conducted experiments by various authorities, and from general experience in boiler practice, it may be concluded that the limit of elasticity for boiler plates may be safely taken at 10 tons per square inch of nett section; but to allow for contingencies it should not be taken at more than $\frac{3}{5}$ the breaking strength of the joints, which is the limit of test pressure to which a new boiler should be strained. This test pressure may also be safely applied to an old boiler whose plates have been exposed only to tensile strains, although they may have varied in intensity many times a day from variations of temperature and pressure. But before such a test is applied to an old boiler its condition must be satisfactorily ascertained by thorough examination of every part both inside and out. Such an examination can, however, only be carried out in certain kinds of boilers, and these require to be completely bared and cleaned for the purpose. Any loss of strength by wasting or grooving of plates, angle irons, rivets, or stays must of course be allowed for in estimating the strength. It may be remarked that the actual strength of a boiler may not be impaired by a wasting in the body of the plate away from the joints, so long as the remaining section is not less than the nett section *through the line* of rivet holes.

When the condition of the boiler after being used for a number of years cannot be satisfactorily ascertained, the testing pressure should not exceed one-fourth the estimated ultimate strength of the joints and stays.

The plates of some boilers are exposed to severe compressive as well as tensile strains, as in the shells of many long externally fired boilers, and in the barrels of some locomotive boilers rigidly attached to the frames. In such cases after long wear the tensile strength of the iron is greatly reduced, and the material is rendered brittle ; but we are in want of information as to its effect on the limit of elasticity. It is, however, probable that the limit of elasticity is not reduced in the same proportion as the ultimate strength of the material, and the same factors of safety as above given may be used for the test pressure, provided that it be gradually applied and the plates are not thrown into vibration by hammering or jarring of any kind.

In deciding upon the proper factor of safety to use for the working pressure we must be guided by circumstances. For a boiler that is thoroughly examined at regular intervals, and whose condition is satisfactorily known, we should be justified in allowing a less margin of safety than with a boiler that is allowed to work without being examined for a length of time, extending perhaps over several years, during which its strength may become considerably reduced. In the former case there would be much less risk in using a factor of safety of only 3 for the working pressure, than in allowing as large a factor of 6 in the latter case. Again, for boilers that are periodically examined we may safely use a less factor of safety when we can depend upon the non-corrosive action of the feed water, dry condition of the flues and surroundings, and uniformity of strain, than when the reverse of these conditions is known to exist.

As a rule we may use for the working pressure of new boilers, or those whose condition is known and regularly ascertained at intervals of from 6 to 12 months, a factor of safety of 5 or even somewhat less, and for those whose condition is not so well known a factor of 6 or 8, according as the nature of each case may demand.

Since the strength of cylindrical flue tubes decreases as the square of the reduction of thickness, whilst the strength of the shell decreases simply as the reduction of thickness, a larger margin of safety for wear should be allowed for the former.

CHAPTER XI.

TESTING.

The only means we have of ascertaining with any degree of certainty the safety of a boiler, is by the application of pressure, which should be under conditions as similar as practicable to those of actual work. Let a boiler be ever so carefully designed and constructed according to the knowledge acquired by careful research and long experience in the strength and disposition of its materials, and let every plate be tested before it is put in, there will still remain an element of doubt as to the actual strength of the boiler since the material may have sustained injuries in the process of construction which have escaped detection. In the case of a new boiler, even by a first-rate maker, to say nothing of original and hidden flaws in the plates, bars, angle irons, and castings, there is always a possibility of defects such as bad welding, careless riveting, plates burnt in flanging or cracked in bending, and many other defects that may be traced to the want of skill or reckless negligence on the part of the workmen.

Many cases of dangerous defects, which the strictest scrutiny of the completed boiler would fail to detect have been brought to light by the hydraulic test combined with careful inspection. The following may be given as examples. In a new boiler the rivet holes in some of the shell plates instead of being about $\frac{13}{16}$ inch diameter were discovered to have been repunched and made 1 inch by $\frac{13}{16}$ in order to get the $\frac{3}{4}$-inch rivets through the holes in the adjoining plate. The section of the adjoining plates through the line of rivets was thereby reduced 14 or 15 per cent. more than necessary, and the strength was further diminished by the presence of incipient fractures produced by the reckless use of the drift. The difficulty, or rather impossibility, of keeping the joint tight in testing by hydraulic pressure led to the discovery of these defects which were certainly *dangerous.*

In another case, the gusset plates of a Cornish boiler were found to be put in between the double-angle irons on the ends, with the material between the holes and edge of the plate nearly all cut away. Such a defect would not be apparent to the eye, being completely concealed, nor to to the ear if tested by sound, yet its presence was revealed by the bulging of the plates on testing the boiler with water-pressure.

These two cases indicate the possible unreliability of the mere internal inspection of a finished boiler, and show that boilers should always be carefully inspected during construction, as well as when completed and ready for work.

There are many boilers which do not admit of anything like proper examination as, for example, locomotive boilers, which, as a rule, are worked with a less margin of safety than any other class. The expense of removing the tubes would alone forbid a periodical examination of the barrel, and the water spaces round the firebox are almost entirely out of sight. Then, again, many forms of marine boilers and the entire small fry of portable, agricultural, and small crane boilers are so constructed that a thorough examination is out of the question. There are also boilers whose construction being unusual or irregular and complicated, defies even an approximate calculation of their strength being made.

Now, in all these cases there is only one means of testing the strength, and that is the application of pressure. The many ways in which this can be applied may be classed under two heads, viz., by steam and by water.

To those who have not been accustomed to it, it may appear the height of madness to test a boiler first by steam in order to ascertain if it be safe at 50 or 25 per cent. lower pressure, as the case may be. This however is to some extent done, but it was once the common practice at many of the boiler works and railway works throughout the country. This practice is neither more nor less than an attempt to explode a boiler in the repairing shed or boiler yard, to see whether it will not explode on the line or at the works of the purchaser. Notwithstanding that hundreds or thousands of boilers have successfully passed through this ordeal, the danger of which is usually aggravated by caulking and hammering all the time at leaky rivets and joints, the principle is inherently bad, and no amount of success which hitherto may have attended it can render the practice justifiable.

In favour of testing by steam, it is argued that it is the only

method by which the conditions of strain can possibly be the same as those under which the boiler is worked. No doubt this is in the main true, but the steam test should only be applied after the strength of the boiler has been ascertained by testing with water.

With regard to the various modes of testing by hydraulic pressure, that commonly adopted is to pump water in until the desired pressure be reached. The condition of the joints and rivets is then looked to, and any very conspicuous distortion or defect probably noted. This is on the face of it only a slipshod and altogether unsatisfactory manner of making the test. Of course, it will depend upon the construction and size of the boiler, and existing circumstances of situation, accessibility, &c., which is the best course to pursue in any given case. In retesting boilers on their seating that have been some time at work, and whose condition has previously, but at no distant period, been ascertained by careful test and examination, the retesting will be sufficiently satisfactory, if, when the pressure is put on the gauge remains stationary, thereby indicating the absence of leakage. At the same time, it is always advisable to examine the flues and rest of the boiler that may be accessible whilst the pressure is on.

In testing a new boiler, before the pressure is applied, the various parts should be measured and gauged, and the results carefully noted. In Cornish and Lancashire boilers each belting of plates of which the internal tubes are made up should be accurately gauged across the diameter, both vertically and horizontally, particularly if the tubes are somewhat oval. The exact spots where the measurements are taken are best indicated with accuracy, by marking them with a centre punch and the dimensions at each place should be written on the plate or othewise carefully noted for checking when the pressure is on. Sometimes, however, the more troublesome plan is used of making a separate rod gauge for each measurement.

It is very troublesome and difficult to measure and remeasure the circumference of a large boiler shell with any degree of accuracy by steel tape lines or other means. The amount of permanent set in cylindrical shells is usually so slight when the boiler is not injured by the test, as to be scarcely perceptible with the rough means employed to measure it. Most attempts to carrying out the system of gauging the circumference have in consequence proved unsatisfactory, and have been abandoned after a short trial. The effect of the pressure

on flat surfaces, stayed or unstayed, however, admits of accurate measurement with simple appliances and with little trouble.

After the test pressure has been maintained some time, the measurements previously obtained should be checked, and any extension, distortion, bulging, &c., carefully noted. Then, again, when the pressure is relaxed, which may be done suddenly, it should be ascertained whether any changes of shape that may have been found are permanent or not. If there be any permanent enlargement or distortion, even of the slightest degree, it should be satisfactorily examined to decide whether it is due to the elastic limit of the material having been exceeded or to mal-construction. There are cases, as, for instance, with flat surfaces, where a permanent set might take place and which would be quite safe at the ordinary working pressure. This is especially the case with stayed surfaces, for it seldom happens that each stay in a series takes its due proportion of load until the stays have been stretched or the plates distorted by the pressure.

But cases of a permanent flue tube distortion or flattening, must always be treated with the greatest caution, since the change of shape is liable to become aggravated on a subsequent application of the same or even a less pressure. In all cases where a permanent set is discovered, the test should be repeated again and again if necessary, to ascertain if the set becomes increased.

Some advocate the method of marking the leaky seams and rivets when the full pressure is on, and then reducing the pressure for caulking. This may appear, however, an unnecessary precaution when testing with water, yet it should always be rigidly carried out when testing by steam. The jarring caused by the caulking is no doubt liable to start the seams and cause fresh leakage when the shell is under severe stress, and in all cases it is perhaps better to reduce the pressure whilst the boiler is being caulked.

Many recommend the employment of hot water for testing, since it assimilates the conditions of stress to those the boiler is exposed to when at work. However, the nearer the heat approaches to the conditions of working, the less capable is the boiler of being gauged and examined, in consequence of the presence of the very heat that is recommended. This fact condemns, in the writer's opinion, the method of using very hot water, as a hydraulic test is comparatively worthless without careful examination at the same time. This objection to hot

testing applies most strongly to tubular boilers where the large tubes are likely to be the weakest portion of the structure, and should consequently be the most carefully examined under pressure. Moreover, the effects produced by the uniform expansion of the whole boiler in using hot water for testing are in many cases very unlike the local expansion of the plates and other effects produced by the fire and hot gases.

A plan has been proposed and in some few cases adopted of filling the boiler with water, closing every outlet and putting a fire to it. As water expands about $\frac{1}{24}$ in volume in rising from 60° to 212°, the rise of temperature as the water becomes heated will cause a corresponding increase of pressure, and from the regularity with which the pressure rises the condition of the boiler can be decided, any jerks or starts of the gauge hand being considered to denote weakness, the soundness, on the other hand, being indicated by the steady rise of the pressure gauge. In using this method of testing, there will be some difficulty in regulating the fire so as to impart the heat in a uniform and regular manner, and also some difficulty in maintaining the temperature for any length of time exactly at the point to correspond with the desired pressure. The use of this plan would of course forbid the examination during the test, at least of the heating surface, and it is very doubtful whether the rise of pressure would be so irregular in most cases as to attract attention in the event of any portion becoming overstrained.

It is most important that any permanent increase of volume should be detected and the following plan for this has been proposed : After the boiler is filled, the quantity of water forced in to raise the pressure is accurately ascertained. On removing the pressure the boiler will contract more or less, and the amount of water forced out, if less than that forced in, will be considered to indicate a permanent dilation of volume. The air in the boiler, to say nothing of that present in the water which, however, could be removed temporarily by boiling, would in most cases destroy the accuracy of this test. In most boilers there are so many places for the air to lodge about the highest points as to cause its entire removal no easy matter. Besides, any leakage during the test would falsify the result obtained by measuring the water, and the springing of the plates on release of pressure would be apt to dislodge more than the amount of water due to contraction of volume alone.

In whichever manner a boiler is tested, too great care cannot be exercised in *obtaining* the exact amount of pressure em-

ployed. The weighting of safety valves is quite unreliable when water pressure is used, and dial gauges are too apt to get out of order to be implicitly trusted when only a single gauge is used. Several curious but serious accidents to boilers have happened through relying upon the indications of a single pressure gauge when testing by hydraulic pressure.

Although a boiler cannot be exploded when water pressure alone is used, a few serious accidents have occurred from the springing of the plates on their giving way under hydraulic test. This is more likely to occur with steel than with iron plates. The spring upon the material, together with the expansion of the compressed air have been known to cause a steel plate to double right back when it has been fractured in testing.

There are many who oppose the system of testing boilers by hydraulic pressure on the ground that it does not tell us the actual strength of the boiler after all. But the same objection may be urged with equal force against the use of a steam test, and the reply to this objection is twofold: 1, the test is not meant for perfectly sound boilers, but for the detection of weakness, which is usually local, and if carefully conducted, the test gives us positive evidence of the presence or absence of such weakness, and of the safety of the boiler at the pressure it is intended to work at, so far as the pressure *per se* is concerned. 2, In order to ascertain the actual strength of a boiler, we should have to burst it, or at any rate so far strain it as to render it worthless, which no sane person would demand for a boiler he intends working.

There is, however, a more sensible argument that applies equally to steam and hydraulic tests, viz.:—A boiler may be strained without detection, beyond its elastic limit, either locally or generally by the test pressure, so as to render it unsafe at the lower working pressure; or, in other words, a high test pressure may render a boiler unsafe which would otherwise have been safe at the lower pressure used in working it. It is feared that any weakness may be aggravated by the test without being disclosed by it. Such a case is certainly within the bounds of probability, and the fact of its possibility should urge the expediency of close inspection whilst the boiler is under pressure.

The danger of seriously injuring the strength by using an excessive test pressure is most likely to occur in the case of tubular boilers, where the distortion of the large tubes becomes *rapidly* aggravated by a lower pressure than that to which the *distortion* in the first place may have been due.

We come now to the question,—How long should the test pressure be maintained? On the one hand, by keeping it on as short a time as possible any serious straining may be prevented and save a weak boiler, but on the other hand, by maintaining the pressure a considerable time—say half an hour or more, it may lead to the detection of weakness which would otherwise escape unobserved. As to the first of these contingencies, a boiler, especially if new, should not be considered sound if unable to bear a pressure considerably in excess of its working pressure for a considerable length of time; besides, a test of short duration is incompatible with efficient inspection. Want of tightness in the joints is often revealed by leakage, only after the pressure has been applied for some time. In explanation, it may be stated that the steam or water leaking from a joint does not always find its way between the plates immediately opposite the point of issue, but the actual source of the leakage, as we may call it, is at some point perhaps several inches distant, whence it requires a considerable time to force its way to the point where it makes its appearance. There can be no doubt that, from the manner in which boilers are usually put together, the internal pressure is not equally resisted by all parts of the shell, and produces an undue and often very severe strain on one plate or portion of a plate. This is probably the cause of many leakages that occur, and which only "take up" after the plate becomes stretched and relieved of the extra strain, and it is therefore advisable in testing, to allow the pressure to act long enough to stretch such weak portions.

As to whether a boiler is strained most severely by steam or by hydraulic pressure, this will be found to resolve itself almost entirely into a question of construction.

A boiler under steam is often strained, especially in a longitudinal direction, more by the greater dilation of the tubes compared with the shell, or by the unequal expansion of the top and bottom of the shell than by the actual fluid pressure. In fact, it would not be difficult to design a boiler that would explode violently with 30 or 40 lbs. of steam pressure, and which would not be unduly strained by 200 or 300 lbs. of water pressure. The persistent leakage at the shell ring seams, along the bottom of horizontal internally fired boilers without external flues, is usually ascribed to the difference in temperature of the water and steam at the bottom and top of the boiler, but *in some cases the leakage* is principally caused by the longitu-

dinal straining of the bottom of the shell, due to the greater expansion of the tubes, especially when the firing is forced in getting up steam after the boiler has been at rest. As this straining would not take place in testing the boiler by hydraulic pressure in the usual manner, this leakage would not be produced. It follows from the above considerations, that a hydraulic test might fail to indicate weakness which would be produced and made apparent by steam pressure.

It is often much more difficult to keep a boiler perfectly tight, and free from oozing at the rivets, plate edges, stays, and tube ends under a very high water pressure than under an equal pressure of steam. This is probably owing to the fact, that the high temperature in the latter case tends to close the joints, and with certain kinds of water any slight oozing is found to take up by the opening becoming closed with deposit or corrosion, which is induced by the high temperature.

It is sometimes urged, that the severe percussive or dynamic force produced by the sudden raising of steam by hard firing, or by suddenly opening and shutting the valves and cocks, strains a boiler more than the dead static pressure which is supposed to be exerted in employing the hydraulic test. But instead of the hydraulic test being a mere dead pressure, the rapid working of the pump often produces a severer sudden strain than can well be produced when there is an elastic cushion of steam in the boiler, and when the pump is carelessly used the inelastic property of the water may render the water test unduly severe. In order to obviate any severe shocks in using the pump, the connection between it and the boiler should be made of a very small area.

In supplying the boiler with water for testing, some engineers always stop the outlets from the boiler before it is quite full, and so retain a quantity of air to act as a cushion when the pressure is applied by the pump.

Although the system of testing boilers by hydraulic pressure to a point considerably above their working pressure has many opponents, its value is attested by the numerous legislative enactments in force for its employment abroad. In most countries the law is more lenient towards old than new boilers, and is not so severe with multitubular as with other boilers, so far as the degree of pressure to be applied is concerned. The reasons for this have been indicated in the last chapter; it may, however, be further remarked that in the case of an old boiler of whose condition there may be some suspicion, the

hydraulic test should not be applied until its form and the strength of plates, as measured by the thickness, have been ascertained by inspection, where this is possible, in order to guard against overstraining. But when this is impracticable, as in many multitubular boilers, one and a half times would be safer than twice the working pressure for the limit of the test.

A boiler that has been at work for some time, and has thus, in a manner, proved its capability of bearing a given pressure, may be considered safe if it will stand a test of one and a half times its working load; even if it has been overstrained by the test, it may still be considered safe for a limited time. The effects of overstraining would probably be detected on a repetition of the test, after the boiler had been working some time, and this appears to be an argument in favour of periodical testing, especially when a reliable inspection cannot be made.

The inspection of boilers should commence at the works where the plates are manufactured, where alone many circumstances connected with their quality can be ascertained.

Many new boilers proved tight and sound on testing at the makers', have been damaged in their subsequent lifting and transit, and still more have been seriously damaged by getting up steam too hurriedly the first time for regular work.

CHAPTER XII.

BOILER EXPLOSIONS.

SAFETY or freedom from liability to explode is the first condition to be sought in using a steam boiler. That this condition is far from being universally attained, is but too well proved by the frequent occurrence of disastrous explosions.

It was formerly the rule which, unfortunately, still to some extent prevails, to attribute explosions to occult causes. Such phenomena as electricity, generation of explosive gases within the boiler from the decomposition of steam, the instantaneous flashing of a large body of water into steam, accounted for by the spheroidal theory or from the superheating of water purged of air, great deterioration in the quality of the plates from chemical changes, and mysterious overheating and superheating have been from time to time urged as causes of boiler explosions, and usually with a confidence and persistence in the inverse proportion to the fitness which would qualify their propounders to speak of them. Unwillingness to know the true cause of an explosion on the part of those interested, as well as inability of others to scrutinise the facts of the case, have, no doubt, been the means of perpetuating much of the speculative nonsense that has been promulgated on this subject.

In this country it has been mainly through the researches and efforts of Sir W. Fairbairn, the engineers of the Manchester Steam Users' Association, and more recently the engineers of the Boiler Insurance Companies, that explosions have been stripped of the mystery in which they were shrouded, and have been ascribed to their true cause. As a rule, steam boilers explode from one cause alone—overpressure of steam. The term overpressure is here used not relatively to the working or blowing-off pressure, but to the strength of the boiler. It often happens that boilers are too weak for the pressure they are worked at, and no accumulation of pressure beyond this *is requisite to* bring about their destruction. The circumstance

of a boiler being unfit to bear its working pressure may be due—1, to its original design and power of resistance not being understood by those who fix the pressure it works at, a common occurrence, arising from ignorance; 2, to the strength, although originally sufficient to bear the working pressure, having been gradually reduced by wear and tear, in which case the error is due to negligence; 3, to the strength of the structure becoming suddenly overtaxed and diminished, as by sudden unequal contraction, caused by unforeseen circumstances or neglect, when its escaping detection until too late may be due to negligence, or, perhaps, in extremely rare cases, to those nondescript causes that swell the chapter of accidents, from which the carrying on of human affairs appears to be inseparable; 4, to defects in workmanship or material, whose presence, in the great majority of cases, can be detected by proper inspection and testing, but which may happen in rare cases to escape the closest scrutiny, and must be placed in the list of humiliating circumstances which remind us of our fallibility.

If we examine these heads more closely, we shall find—1, that ignorance of the principles of construction is exhibited in allowing large flat surfaces to exist without staying, or in wrongly applying intended means to strengthen them. Cases are met with of Cornish and Lancashire boilers converted into plain flat-ended cylindrical boilers, where the neglect to provide for the loss of strength due to the removal of the through tubes can only end in disaster. In some descriptions of internally fired and furnace boilers, the flue tubes, instead of passing from end to end are taken through the shell side, or are made of a horseshoe shape. Their efficiency as longitudinal stays is thus done away with, and when no other stays or means of imparting strength are substituted—by no means a rare occurrence—explosion is likely to follow.

The following are examples of ignorance of design that have led to explosion:—Application of inefficient diagonal stay bars; stay bars attached diagonally to furnace tubes; longitudinal stay bars rendered useless by being bent, or arranged without strutting to clear floats, feed pipes, &c.; girder stays of flat-topped fireboxes and combustion chambers cut away in the middle to clear steam pipes, &c.; absence of stay bolts in flat fireboxes where needed, or stays not made sufficiently strong; attempting to strengthen flat end plates by stiffening instead of staying; absence of encircling strengthening rings or hoops

round large tubes; removing these hoops for fear of leading to overheating; hoops applied in halves without having their ends attached to complete the circle; angle iron hoops partially cut away to clear obstructions; hoops applied to elliptical tubes, as though their efficiency were equal to similar hoops round circular tubes; application of too numerous carrying brackets to the sides of externally fired boilers, so as to interfere with the freedom to expand and contract; cutting away the shell-plates for manholes, domes, and other mountings, without making adequate provision for the loss of strength involved; rigidly attaching boilers to seats or frames, as in locomotives; omitting to stay oval or large circular combustion chambers to shell sides; omitting to provide large weak boiler shells with valves opening inwardly; omitting to allow for spring in the end plates for the expansion of the through tubes in long vertical boilers; omitting to provide against collapse of the closed crowns of the flue tubes in some kinds of vertical furnace boilers; omitting to tie or stay the weak flat bottoms or tops, as the case may be, or vertical furnace boilers; omitting to tie the sides of some descriptions of dry bottom furnace and Butterly boilers.

2. The defects that arise gradually from wear and tear, such as wasting by corrosion and grooving, and which are likely to seriously impair the strength of the boiler, have already been discussed under "Wear and Tear."

3. The strength of the structure, originally sufficient for the pressure, can only become suddenly reduced to a dangerous degree by overheating, or overstraining through too sudden cooling or excessive expansion of flue tubes. Overheating may be caused by shortness of water; by accumulation of deposit or foreign matter on the furnace or flue plates and tubes; by defective circulation; by the metal being too thick near the fire, or by the heat being very intense and concentrated, when even thin plates with moderately pure water are liable to deteriorate; by the accumulation of air and steam in the upper parts of the tubes or cells of "tubulous" and "unit" boilers, from which it cannot escape, in which case the design of the boiler is at fault.

Shortness of water may be due to leakage of joints, valves, or mountings below the water line, or by taps or valves being carelessly left open. It may also be due to excessive priming, or, in vertical boilers containing little water, to a sudden and excessive demand for steam. It is sometimes caused by failure

in the feed supply, either through sheer neglect to turn on the feed in sufficient quantity, or through some accidental or wilful stoppage, breakage, or detachment of pipe. The back pressure valve sticking or becoming inoperative, or absence of any back pressure feed valve, when the water may be forced back through the feed apparatus, or syphoned out from one boiler into another, has often led to shortness of water. It may also be indirectly due to the water gauges, floats, &c., being allowed to get into such bad condition as to be unreliable, and lead to a false reading of the water level.

Accumulation of deposit is usually produced by bad feed water. It may take the form of solid hard incrustation, or of a thick adhesive paste, lying only in certain parts. The accumulation may also act only in thickening the water, which is, however, usually the most dangerous form, as its presence is then least suspected. Foreign matters of various kinds are often added intentionally to remove incrustation, and are sometimes inadvertently left within the boiler after repairs or cleaning. The accumulation is promoted by making the boiler inaccessible for its removal, and by defective circulation.

Defective circulation may be due to the design of the boiler, from its having too cramped water spaces, which defect becomes aggravated by accumulation of incrustation; from water tubes being placed horizontally or with insufficient inclination; from the convection being impeded by overcrowding of tubes, or placing them too close over furnace crowns, and from having too large a body of dead water lying below the heating surface.

Too great a thickness may be due to the use of excessively thick plates; to making the amount of lap excessive; to bad arrangement of furnace strengthening hoops, to careless patching, and to the injudicious application of stays and top hamper on flat firebox and combustion chamber crowns.

The heat may be too intense and concentrated, like a blowpipe flame, as with some arrangements of furnace boilers, where the furnace throat is short, and the hot gases are delivered right on to a plate of the shell or tube, which may be thereby gradually distressed and weakened, or rapidly burnt by the heat driving the water off the surface. The upper portions of horizontal or inclined water tubes being filled with steam, are liable to become overheated and destroyed, either slowly or rapidly, according to the intensity of the heat they are exposed to.

The portions of flue tubes passing through the steam space of vertical boilers, *both large* and small, especially when the area

of firegrate is large in proportion to the heating surfac liable to overheating and collapse. This renders the wo of small vertical internally fired boilers with chimney flue safe when an unusual demand for steam arises, since the fc of the fires is liable to raise the temperature of the flue] to a dangerous degree. Small boilers of this class are a invariably employed where weight and space are limited they should only be used for easy and regular work.

Cases of overstraining through sudden cooling and exc expansion, have already been considered in the chapt "Wear and Tear." It is obvious that overheating from mulation of deposit is most likely to occur in plain cylin externally fired boilers, as the deposit falling from the si apt to become thick on the bottom plates exposed to the i or even over the fire. The same result may happen, how when internally fired tubular boilers are very short in pi tion to the size of firegrate, since the gases may be intensely heated before passing underneath the boiler bo In fact, such a boiler is exposed to some of the same risks externally fired boiler.

4. Defects of workmanship and material are most lial escape detection in small vertical boilers and in multitu boilers of the locomotive and other types where the : cannot be examined unless the tubes are removed or the b are partially taken to pieces. The defects in workma usually found are carelessly punched and fractured rivet burnt or broken rivets, plates damaged by burning, or fr in flanging, dishing, bending, welding, hammering, and p ing, in the boiler yard or during repairs; defective weldi plates and stays, fractures in the ends of brass and small tubes, and carelessly-secured stays. Old plates are freqı seriously damaged by patching them with new plates, i process of removing the rivets, in putting on the new] and also by the greater expansion and contraction of the plate, when the boiler is at work, especially when it is the fire.

Defects of material, such as blisters, lamination, and arising out of the insufficiency in size of the slab from whi plate is cut and adhesion of sand or cinder in rolling can times, but not always, be detected by inspection. Britt of material, unless it be glaringly bad, can seldom b covered by ordinary inspection after the construction c oiler is completed.

Boilers of the full calculated strength are often exploded by an accumulation of steam pressure beyond that assigned to them.

The overpressure may be due to the total absence, or inadequate size or lift, of safety valves or self-acting means of escape for the steam or to the communication between the safety valve and boiler being shut off by some valve or other means. Such an accident may occur when the safety valve is injudiciously placed on the steam pipe, beyond the steam shut-off valve. When the safety valve forms one of a cluster of mountings on one pipe or branch from the boiler, it is a common practice during cleaning and repairs to plug up the aperture of the pipe from the inside, to prevent the dripping of water on those engaged inside the boiler. Now, the risk there is of neglecting to remove the plug, and so endangering the safety of the boiler should never be incurred. The safety valve should, therefore, be always applied as an independent mounting.

Overpressure may arise from the safety valve being recklessly overweighted, by increasing the length of the lever, or the amount of the weight on the lever in valves of this construction. It may be caused by screwing down, tying or wedging fast the lever or dead weight; by the sticking fast of the lever, valve, or spindles in connection, and by the escape pipe, when there is one, becoming plugged up by the water freezing or other accident.

Safety valves of the ordinary lever construction offer the greatest facilities for overweighting, which is sometimes resorted to when the valve is not tight at the working pressure, through faulty design, or for want of re-grinding or proper attention.

Overweighting is also resorted to in order to make the blowing-off pressure agree with the telling of a defective pressure gauge, or from sheer laziness on the part of the firemen when the wish is to save trouble in attending to the boiler. The facilities and temptations for overloading may be diminished by cutting the lever to the shortest length admissible, or when spring balances are used, by preventing the possibility of screwing down beyond a certain point by the application of ferules or other means. By placing the safety valves in a conspicuous and open position, so that the addition of irregular weights may be at once detected and the wedging or tying down rendered difficult, the temptation to overload the valves is reduced. The use of dead-weight valves, of good construction, on

stationary boilers, renders overloading to a dangerous degree no easy task.

A common practice, where little attention is paid to boiler management, is to wedge down the valve, by inserting a chisel or other suitable article between the lever and top of the guide through which it passes.

The sticking fast of the valve may be due to the metal of the lid and seat seizing or wedging tight together, by long contact or excessive pressure; to the bending of the central spindle, or wedging tight of feathers and guides, by expansion, or by the thrust from the spindle or double eye not acting perpendicularly on the valve lid, or by this spindle under the lever sticking fast in the bonnet or stuffing box, when the valve is of the closed-in description. Sticking fast of the lever is often caused by the corrosion of the double eye and pin at the fulcrum end. In order to avoid this corrosion the double eye and pin, and in some cases the lever, are best made of gun metal, or worked on a knife edge, if the condition can be easily ascertained at any moment. It is a mistake to use much grease to the safety-valve lever joints, where there is much coal dust or dirt, as the grease rapidly becomes converted into a sticky mass, that clogs the action of the lever instead of aiding it.

In order to lessen the risk of overpressure from the safety valve becoming inoperative, every boiler should be provided with two safety valves, one of them at least being of the external dead-weight type, for stationary boilers. Lock-up valves cannot be recommended, as they become useless unless frequently eased off their seats.

Other circumstances are to be met with besides gradual accumulation of steam pressure, that may possibly bring about the destruction of a boiler strong enough to bear the ordinary pressure at which the safety valves blow off. The conversion of the static pressure into a dynamic force, by suddenly opening or closing a large steam valve or safety valve, may produce a violent rush of steam and water against the part of the boiler whence the steam is drawn. The percussion of the water and steam in such cases has been known to shake the whole fabric of the boiler. When produced by the sudden opening of the steam junction valve, the percussive action has been known to lift the safety valve momentarily right off its seat, although more than six feet distant from the point of sudden efflux.

A few cases are recorded of boilers being damaged and heating apparatus destroyed by the detonation of explosive mixtures in the flues. Gases are formed and accumulated under certain conditions, from the slow distillation of the coal when the damper is closed. On the fire door being suddenly opened the rush of air mixing with the gas and becoming suddenly ignited produces an explosion. Harmless explosions of this kind on a small scale are very frequent, and it is difficult to explain how violent explosions are not more frequent than they are. The disturbance of a boiler under steam by such a detonation might so strain it as to bring about an explosion at the ordinary working pressure. Cases have occurred of externally fired boilers, standing empty for cleaning, being seriously injured by an explosion of gas, which has found its way through some opening where the valves have been open or fittings removed. On a lighted lamp or candle being applied to the manhole, the mixture of gas and air has exploded with a loud report and fatal result.

Explosions of locomotive boilers have been brought about by the fracturing of the shell, caused by the dome being carried away in coming in contact with tunnels or overhead bridges, or by the shell being pierced by a broken connecting rod when running.

Several cases have occurred of the so-called simultaneous explosion of two or more boilers working side by side. This is usually brought about by the explosion of a single boiler in the first instance, from being too weak to bear the steam pressure, when the projected portions coming in violent contact with the other boilers under steam, and producing rupture, cause their explosion.

When a boiler gives way from overpressure or sudden contraction, a rent may be formed or a piece of plate blown out. The former is the most usual manner of yielding; but in both cases it will depend upon the strength, nature, and arrangement of the material bounding the initial fracture as well as its position, and also upon the pressure, temperature, and amount of water and steam in the boiler, whether the contents will gradually escape through the opening already made, or whether in their violent rush they will increase the extent of opening, and make it easy for the steam behind to tear the boiler into several pieces, and cause a violent explosion.

Now to make this more clear, we shall first consider the influence of *the position of* fracture. Many cases have occurred

of manhole lids on the crowns of horizontal boilers being blown aloft, either from defect of fastening down or defect of material. When the manhole is properly fortified with a mouthpiece or ring the cover is projected aloft, the contents gradually escape through the hole and the boiler is left on its seat (if this be sufficiently strong to withstand the recoil), and probably no further damage is done, except to the boiler-house roof. Should, however, the same accident happen to a manhole cover underneath the boiler, placed near the ground, the effect will be very different, and it will depend upon the weight of the boiler and water contained, size of manhole, pressure of steam, and distance of aperture from the ground, whether the boiler and its contents will be merely raised a little from its seat, or whether it will be shot aloft like a rocket by the unbalanced pressure on the discharge of steam. If the manhole were in the side of a vertical boiler, and near the top, the blowing off of the lid into an open space in front would probably topple over the boiler if it were not well supported.

Again, if the manhole in our first case were without any provision for strengthening the plate surrounding it, and if the edges of the plate were reduced in strength by fractures or corrosion and wear, the rush of steam and water, on the lid blowing off, would probably start a rent in the shell, which a high pressure within the boiler would continue along the lines of least resistance, and the result would be a violent explosion, the severed plates being carried in different directions.

The remarks respecting the blowing away of the manhole cover apply also to the case of a piece of plate being blown out.

It is easy to conceive how an incipient rent in a plate may be carried on by the same pressure that would be insufficient to commence the rent, when we remember how easily a piece of stout paper or cloth is torn through when a rent is made, even so slightly, either at the edge or in the body of the material, or how easily a stick or cane is torn in two when a nick is made in the end. In all such cases the apparent weakness of the material at the initial fracture is due to the unequal manner in which the divellent strain is distributed over the fibres of the material when the rent is once begun.

When the boiler plates are brittle, the vibration caused by a sudden jar, such as is produced by a sudden rush of water and *steam*, may also have effect in continuing a fracture once begun *in a manner* similar to that which causes glass and other brittl

materials to break up so rapidly, once they are slightly fractured.

When one or more portions of a boiler have been separated from the rest, and have been lifted and set in motion by the pressure, it is easy to conceive how the quantity of steam behind given off from a large body of water at a high temperature can propel them to a great distance. The manner in which large masses of plate are completely flattened out shows that the disruptive force has been exerted in all directions, and not merely in one line to which the first rush of steam and water has taken place, as has been assumed by some writers on this subject.

If a cylindrical shell plate gives way by rending through a line of rivet holes, or along a line of grooving or external corrosion, it will greatly depend upon its mode of connection with the adjoining belts of plates whether the rent will extend further than one plate. In the first place, if the rent should occur at a lougitudinal seam, either through the rivet holes or at the edge of the overlapping plate, in a boiler where the riveting extends in a continuous line from end to end, it will probably pass right along through several plates, although they may be strong compared with the plate where the fracture commenced. Should, however, the weak line stop short at the edges of the plate, as when the longitudinal seams break joint, on giving way, the pressure tending to flatten the plate out will cause the rupture to pass through a line of transverse rivet holes or tear off the rivet heads, if the ruptured plate be outside the other plates at the ring seam ; but should the overlap of the fractured plate be inside the other plate, the flattening out will be resisted, and the longitudinal fracture will probably extend to the next plate, still retaining a longitudinal direction or striking off in a diagonal direction, according to the position of the line of least resistance, which will be varied with the manner in which the plate opens out.

Referring to the first of the two cases just considered, such a plate opening out near the crown of a horizontal boiler, or in any part of a locomotive or vertical boiler where the steam and water have plenty of room to escape, will probably only cause damage by the issuing contents, the rest of the boiler remaining undisturbed. But if the rent occur where the escaping steam and water come in immediate contact with a heavy inert mass, as, when the plates rend inside a flue the probable *consequence will* be that the confined steam will pro-

long the transverse fractures, until the boiler is separated into two or more pieces, and project, one or all, to some distance.

Transverse seam rips, which occur most frequently in externally fire boilers, have already been treated of under the head of "Wear and Tear." When these rents occur on the bottom, during the working of the boiler, and the weight of the shell and its contents is very great, the recoil frequently raises one end, when the boiler separates, and the lightest or freest portion is projected endways to a distance.

The absence of longitudinal stays or ties in most externally fired boilers increases the facility of the ends to take leave of each other when once the shell is divided. Should the weight of the boiler and contents be small compared with the pressure, the recoil will probably project the whole boiler aloft, when the expansion of the steam will further separate it, and the pieces will fall in different places.

If the seam rip be confined to a short length, the pressure may be gradually released, without lifting the boiler from its seat at all.

These seam rips on the bottom are sometimes caused by the sudden contraction of the plates on filling the boiler with cold water whilst the bottom is still hot after emptying. When not detected before the boiler is set to work again, the rent may be gently enlarged, as the pressure rises, and allow the contents to escape gradually, without lifting the boiler. Cases have occurred where these seam rips, produced by too sudden cooling, have been of such a size as to allow the water to escape from the boiler as quickly as it entered, on attempting to refill.

When a horizontal flue tube collapses entirely, without fracturing to any great extent, the pressure is usually relieved by the steam escaping through the started seams and small fractures. If such a collapse be sudden, there may be a severe concussion of the air, but no violent explosion, the boiler shell remaining unmoved. But should the tube fracture considerably without parting in two as it collapses, the effects may be very serious, from the rush of hot water and steam. When the rush is towards the confined back end the boiler may be projected forward by the recoil; and, on the other hand, if the contents escape most readily from the front end, the boiler may not be moved from its seat, but the rush of hot water will be liable to cause all the disasters of an explosion, especially when the boiler is in a confined situation. If the tube on collapsing be broken in two, and its efficacy as a longitudinal stay

be destroyed, one or both ends of the boiler may be blown out along with the tube and part of the shell attached, or broken off, where the ends are not well stayed to shell.

In locomotive boilers a collapse of the firebox top plate or yielding of the crown plate in furnace tube vertical boilers, and fracture round the furnace bottom plate, by which the connection with shell becomes severed, are liable to lead to violent explosion, as the reaction consequent upon the downward rush of the contents will carry the boiler aloft.

In investigating the cause of a complicated explosion, the relative weights, positions, shapes of the scattered pieces, and the direction taken by them must first of all be carefully noted, and their original positions in the boiler be assigned to them, along with the positions of the different mountings, manner of staying, and absence or presence of means for strengthening domeholes, manhole, tubes, combustion chambers, &c. The original shape of the shell and large flue tubes should be ascertained as accurately as possible. The primary rent is then to be sought for. In many cases the direction taken by the heavier pieces is a guide to this, as the fractured plates, if free to move, will shoot of, the light pieces along with and in the direction of the first rush of steam, and the heavier pieces in an opposite direction.

That this, however, is not always the case is obvious, as, for instance, when the boiler turns over before separating, or where the direction a piece of the shell would take, if free to move, is changed by part of it clinging for a time to the larger mass to which it may be attached.

All the edges of the plates and angle irons along the lines of fracture should be carefully examined, in search of weak places, such as thinness caused by grooving and corrosion, external and internal, wasting of rivet heads, defective rivet holes, insufficient lap, old flaws and fractures, patching and other signs of repair, indications of softening or deterioration by overheating, condition of low-water indicating apparatus, safety valves and pressure gauges.

A close examination of the shape of the rivet heads and of the shapes and sizes of the plates and arrangement of seams throughout the boiler will usually lead to detection of repairs when these are not obvious at first sight. The colour and nature of the fractures, and whether they be short or jagged, are the only guides to the length of time they have existed, and how they have been produced.

Overheating from shortness of water usually declares itself by the bulging and buckling of the plates, by breaking off the incrustation on one side, and by producing a burnt appearance, along with removal of soot, &c., on the other side, by the starting of the joints and melting of fusible plugs, and in furnace tubes also by forming corrugations parallel with the ring seams. These corrugations are produced by the excessive expansion of the plates at the part where they occur.

It is very seldom that externally fired boilers explode from shortness of water, although their bursting has often been ascribed to this cause. In fact it has long been the fashion, whenever a boiler explosion occurs, to endeavour to attribute it to shortness of water. This is nothing more than an easy method of shifting the responsibility from the makers and owners on to the attendant, who, if not killed by the explosion, in many cases might just as well be, so far as his ability to defend himself is concerned.

Internally fired boilers, on the other hand, frequently do explode from shortness of water.

One or more of the defects above indicated will in most cases be found to be the cause of explosion, which may have occurred at the ordinary working pressure. But if no such defects can be found, and the calculated strength of the boiler be sufficient for the alleged working or blowing-off pressure, the condition of the safety valves, levers, weights, springs, double-eyes, pipes or branches, must be still more closely inquired into, and the strength of the plates at fractures carefully tested. The alleged blowing-off pressure must be carefully checked by calculating the weight upon the valve, and the accuracy of the pressure gauge as well as its condition should be ascertained, and anything else suggested by the nature of the case that may throw light upon the manner in which the overpressure has been brought about.

There are still many who maintain that the violence of some explosions cannot be ascribed to gradually accumulated overpressure, and many theories have now and again been started to account for the tremendous force that is made manifest by its effects.

In seeking to assign such a phenomenon as a boiler explosion to any cause that is known to exist in nature, we must be prepared to show: 1, that the cause can exist in the case in question; 2, that it is competent to produce the results ascribed to it; and 3, that no other known cause can produce these results.

Now if we apply the above standards of reasoning to over-pressure of steam, we know that it often does exist and may in almost any case exist unawares. That it is competent to produce the violent results so often exhibited has been proved theoretically and practically. It has been demonstrated by Professor Airy, that the destructive energy stored up in 1 cubic foot of water in a boiler working at 60 lbs. pressure, is equal to the destructive energy of 1 lb. of gunpowder; and it has been shown by the experiments of the Franklin Institute, that gradually accumulated steam pressure in ordinary wrought-iron boilers can produce a violent explosion. That other causes can produce similar results cannot be disputed, as vessels of compressed air and gases have sometimes burst with terrific effect. On examining, however, the usual effects of a boiler explosion, they are not what we should expect from a discharge of explosive gases, detonating compounds, or electricity, which would act instantaneously and shatter the plates receiving the full force of the discharge into small fragments.

The tearing up of a boiler on explosion although rapid is not instantaneous, and the somewhat gradual developement of the force stored up in the highly-heated water keeps up a continuous pressure behind the separating pieces, which is better calculated to hurl them to a great distance than a force acting instantaneously and suddenly dissipated.

That electricity might be developed in a steam boiler, under certain conditions, there can be little doubt, but it is difficult to conceive how any large quantity can accumulate within a boiler either in direct or indirect communication with the earth.

It has long been known that a current of steam sometimes exhibits electrical conditions. The invention of the Armstrong hydro-electric machine, was suggested by the circumstance of a workman experiencing a smart shock from a jet of steam coming in contact with one hand whilst the other touched the safety valve from which the jet issued. Faraday, who took up the question, proved that the development of electricity was solely due to the friction of the suspended humid particles against the sides of the orifice through which the steam passed; and that it was in no manner due to the change in the state of the water in the boiler. He also showed that the same effect could be produced from the friction of a current of humid air, and that electricity cannot be developed from a current of dry steam or air.

Admitting that the presence of electricity in an ordinary

boiler is not impossible, it yet remains to be shown that it could exist in a state of high tension, and yet, again, how it could bring about an explosion, accompanied by the usual well-known results.

That a small quantity of steam might be decomposed in a boiler by coming in contact with plates that have accidentally become red hot cannot be disputed, but that the decomposition could occur to any considerable extent with oxydised plates is well-nigh impossible. The hydrogen liberated by the decomposition is not explosive, and would require to be united and intimately mixed with its equivalent of oxygen, and then ignited to produce an explosion.

Supposing the oxygen to be admitted with the feed water and that the ignition could be effected by red-hot plates or an electric spark, it still remains to be shown how the gases could possibly become so intimately mixed in presence of the large body of steam and nitrogen present in the boiler as to form a detonating compound. Again, assuming that nearly all the steam could be decomposed, the hydrogen would only burn quietly in the presence of oxygen as it becomes liberated on the red-hot surface of the plates; and in any case, its power to produce an explosion is extremely improbable.

But to take the most extreme view of the case, and assuming the sudden formation of a vacuum within the boiler by the union of the two gases to take place, it is still by no means clear how the bursting of the shell would follow in consequence, as the vacuum formed could only be local and insignificant with a large quantity of steam and nitrogen in the boiler.

With respect to the superheating theory, the *modus operandi* is usually supposed to be something like the following. The plates are allowed to become intensely heated by the water level falling too low or from other causes, and communicate their heat to the steam in the boiler. On the water being agitated and carried aloft as spray, by the action consequent upon the sudden opening of the steam stop valve, safety valve or feed inlet, a large quantity of steam is produced and the pressure suddenly raised above the resisting power of the boiler. That the steam might become highly superheated, and the water in a divided state might be brought into contact with it cannot be disputed. But when we consider the condensation that would take place, and the small total quantity of heat contained even in a large volume of steam, sufficient additional pressure could not be produced to burst a boiler with a reasonable margin of

strength. The increase of pressure can be calculated as follows: In a boiler working at 60 lbs. and having a steam space of 180 cubic feet, suppose the steam to be raised in temperature or superheated from 307° to 800°, the volume would be increased in the ratio of $1 + (0{\cdot}00203 \times 275) : 1 + (0{\cdot}00203 \times 768)$, or of $1{\cdot}56 : 2{\cdot}56$. If the same steam pressure is maintained in the boiler the weight of steam, which in the first instance was 31·5 lbs. will be reduced to about 20 lbs. This quantity of dry steam will have about 18000 units of latent heat, and in falling from 800° to 307° will render $20 \times 0{\cdot}480\ (800 - 307) = 4732{\cdot}8$ units of sensible heat available for raising steam suddenly, or only an amount competent to generate a quantity of steam from water at 307°, equal to about one quarter of that already in the boiler, which would cause a rise of pressure equal to 15 lbs. only. The pressure might also be augmented at the same time by the water coming in contact with the red-hot plates: 30 square feet of $\frac{3}{8}''$ plates heated to a temperature of 900° would give $450 \times {\cdot}114 \times (900 - 307) = 30421$ units of heat in the plates available for sudden evaporation, or sufficient heat to convert about 34 lbs. of water or $\frac{5}{8}$ cubic foot at 307° into steam. As the 180 cubic feet of steam weighed 31·5 lbs. the pressure will be increased by 71 lbs., whence we have a total pressure of $60 + 15 + 71 = 146$ lbs., which certainly might be sufficient to cause an explosion, if the steam were suddenly generated, or more rapidly than it could escape.

But the conclusion arrived at from general experience, and from experiments expressly undertaken by Mr. Fletcher and others to solve this question, is that a large quantity of steam cannot be suddenly generated by throwing water on to red-hot plates. Severe overheating of boiler shells or furnace tubes will start the riveted joints, and offer a further means of escape for the steam as it is formed.

Explosions from overheating are more likely to be produced by the softening and yielding of the plates at the ordinary pressure, or by the sudden contraction of the plates on having water thrown on to them, than by any sudden augmentation of pressure, the production of which is entirely hypothetical. Beyond a certain quantity, the larger the body of water thrown on to a given weight of red-hot plates the less will be the amount of steam formed. It may also be remarked that in ordinary boilers, where the feed inlet is near the bottom, suddenly turning on the feed water will not scatter it over the hot plates near the working water level, where overheating is most

M

likely to occur, but the water will gradually rise up the sides.

The Leidenfrost phenomenon, as it is called, or the tendency of small quantities of water, when thrown on to highly heated plates, to assume the spheroidal condition, and to evaporate suddenly on coming in contact with the plates when the temperature is lowered, has been often adduced as a cause of explosion. The exact application of this theory is, however, by no means clear, and the assumed delay of the water in evaporating is antagonistic to the sudden-evaporation-from-overheating theory. It is difficult to see how the evaporation by ebullition of a large quantity of water in an ordinary boiler could be long delayed, as is assumed in this theory, without reducing the temperature of the water below that sufficient to produce an explosion.

Slight reports in the region of the furnace have sometimes been heard previous to the gradual bulging of the furnace plates from overheating in boilers containing very greasy water. These have been ascribed to the water assuming the spheroidal state, but there is no reduction of the temperature in such cases to account for the sudden evaporation of the supposed spheroids. It may be said of this theory that the conditions it assumes cannot be proved to exist in an ordinary overheated boiler, and that we have no means of knowing whether they would be competent to produce explosion if they did exist.

There is reason to believe that the tendency of greasy water to cohere and resist ebullition through not touching the plates, or, in other words, to become spheroidal, is more likely to be the cause than the effect of the overheating of furnace plates.

When the air usually contained in water has been expelled by boiling, the water, if kept perfectly quiet, can be heated from 70° to 80° beyond its ordinary boiling point without any sign of ebullition; but, on the slightest disturbance or agitation of the water so superheated, a large quantity of steam is suddenly formed. If the pressure above is at the same time reduced, as by drawing off steam, the rush of newly formed steam will carry the water before it with great force against the boiler crown. It is probably this action that produces the concussion sometimes felt when standing on a boiler whilst the steam is suddenly drawn off on starting the engine. Under certain conditions the sudden generation of steam might produce a pressure above that at which the safety valves are set to *blow off*, and this, together with the force of impact might

bring about the explosion of a very weak boiler, but not of one having a proper margin of strength.

The practice of ascribing steam-boiler explosions to obscure causes has been productive of much mischief, as it engenders a carelessness on the part of owners and attendants, who have been led to believe that no amount of care will avail against the mysterious agents at work within a boiler.

Considering the too frequent want of care and knowledge on the part of those having the charge of boilers, and the great number of dangerous defects that are almost daily discovered by trained inspectors, the mystery to be solved is—how so many boilers escape explosion at the ordinary working pressure, and not,—what has been the cause of the disaster when an explosion does occur?

The reader will find much valuable information about the causes and prevention of boiler explosions in the monthly reports of Mr. L. E. Fletcher, Chief Engineer of the Manchester Steam Users' Association; and in the annual reports of Mr. E. B. Marten, Chief Engineer of the Midland Steam Boiler Inspection and Assurance Company; of Mr. R. B. Longridge, of the Boiler Insurance and Steam Power Company; and of Mr. Hiller, of the National Boiler Insurance Company.

CHAPTER XIII.

COMBUSTION OF COAL.

COMBUSTION is the name given to any rapid chemical union attended with great heat and light. The combustion that takes place over our fire grates and gas burners, is the chemical combination of oxygen with carbon and hydrogen. The oxygen is supplied by the air where it is associated with nitrogen, from which it readily separates. The carbon and hydrogen are present in the fuel and gas, and on being sufficiently heated by the application of a light or other well-known means, the attraction between them and the oxygen becomes strong enough to cause them to combine with it. The application of heat is necessary to start the process of combustion, which is simply one of rapid oxidation; but the chemical change afterwards produces more than sufficient heat to carry it on. The production of heat by combustion is usually ascribed to the impact of the atoms of oxygen against those of the other combustible, as they clash together on entering into chemical combination.

The amount of heat produced by the combustion of different bodies, or their total heat of combustion, has been approximately determined by experiment, and is usually expressed in pounds of water raised 1° Fahrenheit (or conversely, in number of degrees 1 lb. of water is raised) by 1 lb. of substance combining with oxygen. The standard unit of heat in this country, or British thermal unit, is the quantity of heat that will raise 1 lb. of water 1° Fahrenheit at its greatest density, which is at a temperature of 39·1°.

All substances combine chemically in certain proportions only, both by weight and volume, which are called their chemical equivalents. The equivalents by weight and volume of the elements and compounds with which we are concerned, are given in the annexed table, from which the combining proportions of the combustible substances can be readily calculated.

Chemical and physical properties of the elements and products of combustion.

	Symbol.	Chemical equivalent by weight.	Chemical equivalent by volume $\square=1$.	Specific heat by weight.	Specific gravity at 62°.	Cubic feet in 1 lb. at 62°.	Weight of a cubic foot in lbs. at 62°.
Oxygen	O	16	$\boxed{O}$	·2174	1·106	11·88	·0841
Nitrogen	N	14	$\boxed{N}$	·2438	·971	13·53	·0739
Hydrogen	H	1	$\boxed{H}$	3·405	·0691	190·11	·00526
Carbon (as gas)	C	12	$\boxed{C}$				
Sulphur (as gas)	S	32	$\boxed{S}$				
Air	N_4O	72	$\boxed{N}\boxed{N}\boxed{N}\boxed{N}+\boxed{O}=\boxed{N}\boxed{N}\boxed{N}\boxed{N}\boxed{O}$	·2374	1·000	13·14	·0761
Water	H_2O	18	$\boxed{H}\boxed{H}+\boxed{O}=\boxed{H_2O}$	1·000	819·4	0·016	62·355
Carbonic Acid........................	CO_2	44	$\boxed{C}+\boxed{O}\boxed{O}=\boxed{CO_2}$	·2163	1·529	8·60	·1163
Carbonic Oxide	CO	28	$\boxed{CO_2}+\boxed{C}=\boxed{CO}\boxed{CO}$	·2450	0·967	13·60	·0736
Olefiant gas........................	C_2H_4	28	$\boxed{C}\boxed{C}+\boxed{H}\boxed{H}\boxed{H}\boxed{H}=\boxed{C_2H_4}$	·4040	0·978	13·44	·0744
Marsh gas	CH_4	16	$\boxed{C}+\boxed{H}\boxed{H}\boxed{H}\boxed{H}=\boxed{CH_4}$	·5929	0·554	23·75	·0421
Aqueous vapour	H_2O	18	$\boxed{H}\boxed{H}+\boxed{O}=\boxed{H_2O}$	·4805	0·622	21·14	·0473
Sulphurous Acid........................	SO_2	64	$\boxed{S}+\boxed{O}\boxed{O}=\boxed{SO_2}$	·154	2·247	5·85	1·710

The condensation of the elementary bodies by chemical combination is shown in the fourth column. The elements in atmospheric air are not chemically combined. Carbonic oxide is not formed directly from the union of the elements carbon and oxygen, but from the union of the compound carbonic acid with oxygen.

The volume of a given weight of gas at any temperature, can readily be ascertained from the sixth column as follows:—Let V = volume at 62°, and V′ = volume at any required temperature t', then $V' = V\left(\frac{461 \cdot 2 + t'}{523 \cdot 2}\right)$.

Carbon, almost the only element contained in good coke, and the principal element in coal, combines with oxygen to produce two different gases, according to the proportions in which the combination is effected, viz., carbonic acid when the combustion is perfect, and carbonic oxide when the combustion is incomplete. The acid is composed of one equivalent by weight of carbon (C_{12}) and two of oxygen (O_{32}), or 1 lb. of carbon combines with $2\frac{2}{3}$ lbs. of oxygen and forms $3\frac{2}{3}$ lbs. of carbonic acid gas. The carbon which is solid in the fuel passes during combustion into the gaseous state. The volume of the carbonic acid gas is equal to that of the original $2\frac{2}{3}$ lbs. of oxygen, and the quantity of heat produced by the combination is 14,500 units, as given in the table on page 251. This would be the amount of heat from the combustion of every pound of carbon in the furnace, if completely consumed; but, should the layer of incandescent coke or carbon be thick in proportion to the quantity of air supplied through the fire grate, the oxygen of the carbonic acid will recombine with another 1 lb. of carbon, and form $4\frac{2}{3}$ lbs. of carbonic oxide gas. By this second combination the volume of the gas is doubled, and a large amount of heat is rendered latent in performing the interior work of expanding the gas and converting the solid carbon into vapour. The heat produced now falls from 14,500 units to 8800 units, the amount due to the imperfect combustion of 2 lbs. carbon, showing a loss of sensible heat equal to 5700 units. When the combustion stops at this stage for want of air, the loss of sensible heat and waste of fuel is evidently very great. But when a sufficient supply of fresh air is at hand, the $4\frac{2}{3}$ lbs. of oxide recombine again with an additional $2\frac{2}{3}$ lbs. of oxygen, making $7\frac{1}{3}$ lbs. of carbonic acid gas. The volume is hereby reduced to that of $5\frac{1}{3}$ lbs. oxygen, and the 5700 units of latent heat are rendered sensible, the

total quantity of heat due to the last combination being 8800 + 5700 + 14,500 = 29,000 = the amount due to the perfect combustion of 2 lbs. carbon.

The total heat of steam at atmospheric pressure being 1178·1, 1 lb. of carbon should convert

$$\frac{14,500}{1178 \cdot 1 - 62} = 12 \cdot 91 \text{ lbs. of water at } 62^\circ$$

into steam of atmospheric pressure.

This is assuming a perfect evaporative efficiency, and all the heat to be utilised. The best results in practice, however, fall far short of this. In locomotive boilers, where the best coke, consisting almost entirely of carbon is still, although rarely, used, the maximum evaporation under favourable conditions may be taken at 9·5 lbs. of water from 62°, showing a loss of about 20 per cent. of heat. The reason of this will be shown below.

Hydrogen is not supplied in the free state to our furnaces, but is usually present as a component of the hydrocarbons, such as pitch, tar, olefiant gas, &c. contained in the coal. Two equivalents, by weight, of hydrogen (H_2) combine with one of oxygen (O_{16}), or 1 lb. of the former with 8 lbs. of the latter, and form 9 lbs. of water which pass off in a state of vapour. The quantity of oxygen is, in this case, three times as much as we had for the carbon. By volume, two of hydrogen combine with one of oxygen, the resulting aqueous vapour having the same volume as the hydrogen. Its calorific power being 62,032 units, we have then by 1 lb. of hydrogen—

$$\frac{62,032}{1178 \cdot 1^\circ - 62} = 55 \cdot 58 \text{ lbs. of water at } 62^\circ$$

converted into steam of atmospheric pressure.

When hydrogen and oxygen are present in the fuel in the the proportions to form water, they combine as such, and do not increase the heat of combustion ; but, along with any other water that may be present, act injuriously in reducing the temperature of the furnace by absorbing a considerable amount of heat by their conversion into vapour. In order to ascertain the heating power of hydrogen contained in any fuel along with oxygen, we have to subtract one part by weight of the former, for every eight parts of the latter, and consider only the surplus hydrogen as having any heating power.

The hydrocarbons are the first constituents of coal acted upon by the heat of the furnace, and pass readily into the gaseous state which they must assume before they are burnt. To the volatile nature of the hydrocarbons is due the flaming property of the coals containing them.

The different kinds of coal such as non-bituminous or anthracite, slightly bituminous or anthracitic, semi-bituminous, and bituminous, of which an analysis is given in the annexed table, can be distinguished by their appearance, but the character of different varieties of each kind cannot always be determined by the colour, lustre, cleavage, &c., as many suppose.

The Anthracite, or hard stone-like coal of South Wales, is lustrous in appearance. It is difficult to burn, requiring a very strong draught, high temperature, and considerable attention. When dry, it burns without flame or smoke, like coke, since it contains no hydrocarbons, and, although it gives out an intense local heat, it is not adapted for burning in a steam boiler furnace, and is consequently little used as a steam coal.

Slightly bituminous, or Anthracitic coal, found abundantly in South Wales, contains a small amount of hydrocarbons, and is, for many kinds of boilers, decidedly the best steam coal we possess. No further proof of this is required than the large price it fetches for marine boilers, where semi-bituminous coal of good quality is to be had at a much cheaper rate. It is a free burning coal, usually with a short flame, and requires little attention. It swells considerably, and falls rapidly to pieces in the furnace, but does not cake, and the best qualities yield but little clinker and ash. It is often called smokeless, but most of the best qualities emit a light vapoury smoke. It will not bear rough usage, and crumbles rapidly after long exposure to the atmosphere, which circumstance, together with the quantity lost in some descriptions by falling through the fire bars in consequence of its decrepitation by the heat, causes a large waste, often equal to 15 per cent. In consequence of this it is often advisable to mix this with a harder kind of coal, to enable the dust to be utilised. The small amount of skill and attention for smokeless and economical firing it requires when compared with most kinds of semi-bituminous coal, is actually the circumstance to which its greater value is due.

The semi-bituminous coal containing a considerable, but varying amount of hydrocarbons, is more used than any other kind for steam boilers. Some descriptions are free burning,

Chemical Composition of various kinds of Coal and of Coke.

	Northumberland and Durham.			Durham Coke.	South Wales.		Lancashire.		Derbyshire.	Scotch.	
	Semi-bituminous.				Slightly Bitu-minous.	Anthra-cite.	Semi-bitu-minous.	Bitu-minous.	Semi-bitu-minous.	Semi-bitu-minous.	Bitu-minous.
	Best House Coal. Much smoke.	Best Steam Coal. Much smoke.	Coking.		Best Steam Coal. Little smoke.	No smoke.	Steam Coal. Much smoke.	Gas Coal.	House and Gas Coal.	Steam Coal. Much smoke.	Boghead Cannel. Gas Coal.
Carbon	84·3	82·4	86·8	93·2	88·3	92·3	82·6	80·1	79·9	80·1	63·1
Hydrogen ...	5·5	5·4	5	·7	4·7	3	5·9	5·5	4·8	6·5	8·9
Oxygen	6·2	6·4	5·2	·9	·6	2·6	7·4	8·1	11	8	7
Nitrogen......	2·1	1·6	1	1·3	1·4	·6	1·8	2·1	1·2	1·6	·2
Sulphur	1·2	1·3	·9	...	1·8	...	·8	1·5	·7	1·4	1
Ash............	.7	2·9	1·1	3·9	3·2	1·5	1·5	2·7	2·4	2·4	19·8
Total	100	100	100	100	100	100	100	100	100	100	100
Coke °/。......	75	35·6	72	...	84	55	64	60	58	55	30

whilst others cake very much; all of good quality burn easily with an ordinary draught, and emit a considerable amount of smoke unless special care is used to prevent it.

The best steam coals of this class are chosen for their small amount of ash and clinker, hardness, and non-caking quality, which tend to diminish the attention required to burn them economically. The properties of semi-bituminous coal vary considerably, and it is almost impossible to tell the quality from the appearance, apart from such defects as are indicated by the presence of stone, iron pyrites, or other foreign matters. Many rich, small, hot coals that are not suitable for boiler furnaces when used alone, owing to their tendency to cake, can be successfully burnt if mixed with a harder free burning coal; and, indeed, the best results both in evaporation, speed, and economy, are to be obtained by a judicious mixing of two or more properly selected descriptions of coal. Bituminous coal contains more tarry matter than the above, and is best utilised for gas making.

The kind of coal containing the largest amount of bitumen, of which the Boghead Cannel may be taken as a type, although rather an extreme one, being regarded by some as not being a coal at all, is without lustre, of a greyish or brownish black colour. It yields a very large quantity of ash and clinker, and is not suitable for steaming. It is employed almost exclusively for gas making, for which the large amount of contained hydrocarbons renders it most suitable.

Coke is the solid carbon and other material left after the volatile ingredients are driven off by partial combustion in coke ovens, or by slow distillation in flue retorts. The former is much the best for boiler fuel. Much small semi-bituminous caking coal, rich in carbon, but which would be comparatively worthless for boiler furnaces, forms into large pieces in the coke ovens, and becomes a valuable coke for locomotive boilers.

Some patent fuels are also made by compressing into moulds and heating in retorts, small coal of good quality, that would otherwise be wasted. It is thus formed into compact solid blocks, without the expulsion of the hydrocarbons. Pitch or other combustible substances may be added when the coal does not contain a sufficient quantity of bituminous or pitchy matter to make it cohere properly.

Theoretical heat of Combustion of different kinds of fuel and their constituents.

Name of Fuel.	Composition. C	Composition. H	Composition. O	Lbs. of oxygen required for combustion with 1 lb. of gas.	Lbs. of air required for combustion with 1 lb. of gas.	Calorific power. Total heat of combustion of 1 lb. of compound, in thermal units.	Calorific power. Relative heating power.	Lbs. of water evaporated from 212.
Hydrogen	...	1·00	...	8	36	62,032	427	64·2
Marsh gas	·75	·25	...	4	18	23,883	164	24·3
Olefiant gas	·86	·14	...	$3\frac{3}{7}$	$15\frac{3}{7}$	21,344	147	22·1
Carbon—burning to CO_2	1·00	...	...	$2\frac{2}{3}$	12	14,500	100	15·0
Carbon—burning to CO	1·00	...	...	$1\frac{1}{3}$	6	4,400	30	4·5
Carbonic Oxide	·43	...	·57	$\frac{4}{7}$	$2\frac{4}{7}$	4,328	29	4·4
Coal.								
Average Welsh	·838	·048	·041	...	...	14,819	102	15·3
,, Newcastle	·821	·053	·057	...	...	14,746	102	15·3
,, Scotch	·785	·056	·097	...	...	13,675	94	14·2
,, Derbyshire	·795	·049	·101	...	...	13,761	95	14·2
,, Lancashire	·779	·053	·095	...	...	13,410	93	13·9
Coke	·94	·0004	·007	...	...	13,630	94	14·1
Peat (dry)	·60	·06	·31	...	...	9,941	68	10·0
Wood	·50	·06	·41	...	...	7,871	54	7·9
Sulphur	...	...	...	...	...	4,032	28	4·2

The total heat of combustion of a substance such as coke or coal can be found by taking the sum of the quantities of heat which are given by the combustion of its component parts taken separately. If we take, for example, the quality of coke given in the above table, we have for the total heat of combustion when completely burnt ·94 lb. carbon $\times$ 14,500 = 13630 units. This does not, however, give us the temperature of the resulting carbonic acid. To find this, the heat of combustion must be divided by the total weight of the gas multiplied by its specific heat, which we assume here to be constant at all temperatures. We have also to consider the loss of tempera-

ture due to the absorption of heat by the nitrogen, which forms the principal bulk of the air for combustion,

$$
\begin{aligned}
\text{Weight of oxygen} &= 2{\cdot}51 \text{ lbs.} \\
\text{,, nitrogen} &= 8{\cdot}816 \text{ lbs.} \\
\hline
& 11{\cdot}326 \text{ lbs. of air.}
\end{aligned}
$$

Carbonic acid	3·45 lbs.	×	·216	=	·745
Nitrogen	. 8·82 lbs.	×	·244	=	2·152
					2·897

Therefore elevation of temperature above atmosphere

$$= \frac{13630}{{\cdot}2{\cdot}89} = 4716^\circ \text{ Fahr.}$$

For the more complicated process of combustion, when coal is burnt, let us examine that of 1 lb. of average Newcastle coal. Here we have—

Carbon	=	·821 lbs.
Hydrogen	=	·053 lbs.
Oxygen	=	·057 lbs.

Making allowance for the water due to the presence of the oxygen and hydrogen together we get—

$$\text{Hydrogen} = \left({\cdot}053 - \frac{{\cdot}057}{8}\right) = {\cdot}046.$$

The quantities therefore stand—

Carbon	=	·821 lbs.
Hydrogen	=	·046 ,,
Water	=	·064 ,,

Carbon	·821	×	14500	=	11904	units of heat.
Hydrogen	·046	×	62032	=	2853	,,
					14758	units of heat =

tal heat of combustion—

$$\begin{aligned} \text{Oxygen required for } C\ O_2 &= 2{\cdot}18 \text{ lbs.} \\ \text{,, \quad ,, } H_2\,O &= {\cdot}368 \text{ lbs.} \\ \text{Total oxygen consumed} &= 2{\cdot}548 \text{ lbs.} \\ \text{Associated nitrogen in air} \quad . &= 8{\cdot}918 \text{ lbs.} \\ \text{Total quantity of air consumed} \ . &= 11{\cdot}466 \text{ lbs.} \end{aligned}$$

esulting carbonic acid . . . 3 lbs. × ·216 = ·648

eam $\left\{\begin{array}{ll} \text{Water in coal} \ . \ . & {\cdot}064 \\ \text{,, from hydrogen burnt} \ . \ . & {\cdot}414 \end{array}\right\}$ ·478 lbs. × ·480 = ·229

itrogen . . . . . 8·918 lbs. × ·244 = 2·176

3·053

To find the elevation of temperature in this case we must duct the latent heat in the steam from the total heat of comistion, when we get—

$$\frac{14758 - (966^\circ \times {\cdot}478)}{3{\cdot}053} = 4682^\circ = \text{elevation}$$

temperature above the atmosphere.

We find from the above results that the total heat of comistion of coal compared with that of coke is greater, whilst e elevation of temperature of the products is less. This is ring to the heat absorbed in raising the temperature of the creased quantity of air required in burning coal, and also in nsequence of the heat rendered latent in evaporating the iter in the fuel. The respective temperatures here assigned e never realised in practice, owing to the cooling effect of the iburnt air, plates and material in the furnace. The quantity heat absorbed by the ashes and other ingredients in the fuel, iich is however comparatively small, should also be taken into count in estimating the exact temperature due to the combuson of any fuel.

The theoretical amount of air required for any given fuel pends upon the chemical composition of that fuel, and may

be obtained by the following formula where A = weight of air required—

$$A = 12\ C + 36\left(H - \frac{O}{8}\right)$$

For all kinds of coal and coke the minimum weight of air required may be taken at 12lbs. per lb. of fuel, the variation on either side of this quantity being immaterial.

It must not, however, be assumed that coal or coke can be properly burnt in a boiler furnace with anything like so small an amount of air as this. Since carbon cannot be economically burnt in the presence of the carbonic acid formed, this gas must be diluted with a considerable quantity of oxygen or air to be ready for combustion with the carbon it meets with. This necessary reserved quantity of air for dilution will vary in amount according to the manner of its distribution, and the velocity with which it is forced amongst the burning fuel.

When the pieces of coal are small and of a caking nature they form into a large solid mass over the bars, restricting the passage of air to a few spaces, especially when the draught is moderate, and a large amount of oxygen passes in consequence unburnt through the fire. When the draught is severe good coking coal can be burnt with a good result, and some descriptions of this coal are highly prized by those who know how to use them. With slightly bituminous or semi-bituminous non-caking coal in large or small pieces the bulk of air passed through the grate is more or less minutely divided, and more favourably diffused for combining with the carbon.

From various experiments conducted under different circumstances it appears that for an ordinary chimney draught the weight of air required for dilution may be taken as equal to that required for combustion. This gives us 24 lbs. as the quantity of air required for each pound of fuel. But when the air is driven with great velocity by a strong draught amongst the burning fuel the combination with the oxygen is more readily effected, and a smaller quantity of air is required. With very powerful chimney, or artificial draught, the weight of extra air required is found to be considerably less than the above, and may be taken as one and a half the minimum quantity, making 18 lbs. per lb. of fuel.

In burning semi-bituminous steam coals a considerable quantity *of fresh* air is required for combining with the hydrocarbons

above the layer of coal, and must be admitted directly to the gases either at the furnace front or at the bridge, or, which is perhaps better, at both, unless the furnace is specially designed for air admission to the sides or middle of the space above the fuel. Whichever plan is adopted too great care cannot be taken to admit the air in small jets by perforations or other means, especially when its direction is parallel with the current of gases. This ensures a better mixing, and prevents to a very material degree the undesirable cooling effect of introducing a large volume of cold air in one place, which is liable to defeat the end for which it is introduced.

As the chemical action between the fuel and the oxygen can only take place when the two are in intimate contact, the rapidity and completeness of combustion and intensity of heat will be increased by increasing the number of points of contact, or by reducing the size of the pieces of fuel. The ultimate conclusion to be drawn from this is that coal should be used as dust, or, still better, as gas, in order to afford the greatest facilities for perfect combustion. No doubt this conclusion is theoretically correct, and the latter mode will in time be brought largely into practice. The principal difficulty in the employment of these methods, especially the former, is to arrive at and apply successfully the proper quantity of air for admixture.

With boilers having a good chimney it is usual to have a damper for regulating the draught or altering the quantity of air admitted. For every description of boiler the most economical rate of air admission will depend upon the general and detailed arrangement of furnace, quality of coal, ratio of grate area to effective heating surface, &c. When this rate is exceeded, or, in other words, when the fire is forced, it does not of necessity follow that a large amount of unburnt oxygen will escape to the chimney. Whether this will take place or not will depend upon the distribution and thickness of coal on the grate, facility afforded for mixing the air with the gases as they leave the furnaces, and amount of air introduced otherwise than through the fire bars. It may happen, as indeed it usually does with skilful firing, that the quantity of free oxygen in the chimney decreases as the force of the draught is increased, since the quantity of the coal properly consumed increases still more rapidly, in consequence of the more intimate contact with the oxygen caused by the more rapid draught.

The evil of forced firing is generally to be found in the fact that the increased velocity of the gases diminishes the efficiency

of the heating surface, as will be shown below, the quantity of heat extracted by the boiler depending upon the length of time the products of combustion are allowed to be in contact with the absorbing surface.

Should, however, the volume of unburnt air discharged into the chimney increase with the forced firing the result will be a waste of heat equal in amount to that absorbed by the increased quantity of air admitted, in addition to the loss due to the increased velocity of the gases.

When the supply of air is too small imperfect combustion is the result, causing either smoke or the formation of carbonic oxide, or both, according to the nature of the fuel and distribution of the air. The loss of heat owing to the formation of carbonic oxide is frequently 25 per cent. of the whole amount due to the most economical supply of air. The carbonic oxide is invisible, but its presence is sometimes revealed, especially in coke burning, when on opening the fire door it burns with a blue flame, as it becomes ignited by contact with the cold fresh air. When burnt with oxygen at a high temperature the colour of the flame is yellow.

Dry carbon burns without flame. When flame is seen above a coke or charcoal fire it is caused by the burning of carbonic oxide, or of hydrogen, which has found access to the fire either in the moisture absorbed by the fuel, or from some steam or vapour passing through the bars with the draught.

If we take the actual quantity of air required for burning coke as $\frac{3}{2}$, and that for semi-bituminous coal as double the theoretical quantity, we shall find the elevations of temperature to be respectively 3215° and 2478°, the total heat of combustion being as above 14630 units and 14758 units.

The distinction is here seen between the total heat of combustion and the temperature of the products of combustion, or between the quantity and intensity of heat, the latter being much greater in fuel containing little or no hydrogen, although a less quantity of heat is produced. The cause of this is evident: in burning, carbon requires for its perfect combustion but one third the weight of oxygen or air required by an equal amount of hydrogen, producing a corresponding small weight of carbonic acid, compared with the steam produced by the combustion of the hydrogen. Again, the specific heat of carbonic acid gas is less than one-quarter that of steam, and it is upon the weight and specific heat of the products of combustion that *their temperature* depends as well as their total heat of com-

bustion. Moreover, in burning dry carbon or coke, there is but little or no steam to render latent any of the heat.

But the intensity of the heat given out by a piece of coal during its combustion will be proportionate to the rapidity with which it burns. The element of time is therefore of great importance in considering the heating effect of any given kind of fuel. The theoretical intensity of heat of two different qualities of coal, calculated from their chemical analysis, might be nearly alike, yet, with the same ordinary draught one kind might be a quick burning "lively" coal, of loose structure, developing an intense heat during its rapid combustion in a boiler furnace, whilst the other may be very compact and slow burning, the heat developed not being intense compared with the first. The calorific intensity of slow burning coal is diminished by the loss of heat that takes place by conduction and radiation.

Although the combustion of hydrogen produces the largest amount of heat of any known combustible under favourable conditions, the large quantity of air required for its combustion in an ordinary boiler furnace renders the attainment of a high temperature by it impossible.

The reason is thus obvious for making coal into coke and wood into charcoal when a very high temperature is required. A given quantity of coal properly burnt, and where the heat is all utilised, will evaporate more water than the same weight of coke, but twenty times the weight of coal cannot in practice be made to produce the same temperature that is produced by the coke, and this is why it is so valuable for smelting purposes where an intense heat is required and where the products of combustion are brought into contact with the material to be heated.

The following are the temperatures T produced by the perfect combustion of 1 lb. of substance with its minimum quantity of air, and T′ the temperature of 1 lb. with oxygen without nitrogen :—

$$\text{Hydrogen}: T = \frac{62032-(966^\circ \times 9)}{(28 \times \cdot 244) + (9 \times \cdot 480)} = 4783^\circ \;\&\; T' = 12346^\circ$$

$$\text{Carbon}: T = \frac{14500}{(3\cdot 67 \times \cdot 216) + (9\cdot 33 \times \cdot 244)} = 4723^\circ \;\&\; T' = 18308^\circ$$

$$\text{Carbonic Oxide}: T = \frac{4328}{(1{\cdot}57 \times {\cdot}216) + (2 \times {\cdot}244)} = 5233^\circ$$

$$\text{and } T' = 12738^\circ$$

$$\text{Olefiant Gas}: T = \frac{21344 - (966^\circ \times 1{\cdot}287)}{(3{\cdot}145 \times {\cdot}216) + (1.287 \times {\cdot}48) + (12 \times {\cdot}244)} = 4758^\circ$$

The flame of a fire is usually not so hot by contact as the incandescent fuel. With many anthracite coals which require a strong draught and a high temperature for their combustion, the intense heat is concentrated near the fire bars, rendering them liable to waste. In order to prevent this the method has been employed of placing water beneath the fire grate, which on evaporating passes through the fire above, and is decomposed into its constituent oxygen and hydrogen. The latter, on burning with flame, distributes the heat better through the furnace, and renders it more effective for heating crucibles or other articles, only a small part of which are brought into contact with the incandescent coal.

In practice, the whole available quantity of heat produced in a boiler furnace is never utilised. There is usually a large amount lost by radiation, which will depend upon the arrangement, condition, and material of the furnace, and may be taken as a rule at from 5 to 10 per cent. The amount of heat lost by the hot ashes, clinkers, and fuel falling through the bars varies from $1\frac{1}{2}$ to 15 per cent. In ordinary practice it may be taken at 10 per cent. There is a large amount, seldom less than 25 per cent., wasted by the gases escaping at a high temperature, from 400° to 700° into the chimney. The total amount available for evaporation is therefore but 60 per cent. in the best average practice with internally fired boilers. The average amount utilised in externally fired boilers is only about 50 per cent.

In using coal containing a large amount of hydro-carbons, a great loss often occurs by their escaping unburnt. With care this loss may be, to a great extent, avoided, yet some authorities estimate the evaporative power of various classes of coal by the amount of fixed carbon they contain.

Taking the temperature of the escaping gases on leaving the boiler to be the same for coke and coal, say 600° or 538° above the atmosphere, which is the average temperature to ensure the best draught we have for coke, with $\frac{3}{2}$ air for dilution, $538^\circ \times {\cdot}24 = 2281$ units of heat; and for coal, with 2 air for dilution,

$538° \times 5.77 = 3104$ units. These are equivalent to an evaporation at 212° of 2·3 and 3·2 lbs of water respectively per pound of fuel.

This shows that there is a greater loss in the escaping gases from the combustion of coal as compared with that of coke, on account of their greater weight and specific heat, and the heating surface should therefore be made proportionately greater, or the grate area less, to obtain the same evaporative efficiency, other conditions of evaporation being equal in both cases.

Apart from indicating the presence of ash, sulphur, and other deleterious ingredients, and the decided scarcity, or otherwise, of hydrogen and oxygen, the ultimate composition of any description of coal affords but little assistance in determining its value for different purposes. Nearly the same quantities of elements in different coals may arrange themselves before and during combustion, so as to produce very different series of compounds. Analysis shows but slight difference in the quantities of the ingredients present in the best house, steam, coking and gas coals of the semi-bituminous and bituminous kinds, and yet the difference in the comparative quantities of coke and gas they yield is very great. It is only by actual trial under different conditions of combustion that the value of any kind of coal can be ascertained. Nor can the theoretical calorific value deduced from the chemical composition be taken as a certain indication of the evaporative value attainable in practice. No doubt evaporative results from various kinds of coals bearing the same proportion to their theoretical calorific power can be obtained by carefully constructing and managing the furnace and boiler to suit the coal to be burnt; but of two kinds of coal giving about equally good evaporative results when burnt to their best advantage, that requiring the least amount of attention in firing will naturally be most highly prized.

Numerous experiments, with conflicting results, have been conducted by the rival North country and South Wales coal-owners to determine the comparative value of the steam coals from their respective districts. The most trustworthy results of these experiments are given in the annexed table. These were obtained under conditions favourable to the combustion and absorption of heat from the best descriptions of each kind of coal, which prove that there is but little difference in their evaporative value, when the hydro-carbons of the semi-bituminous North country coals are properly and effectively consumed ;

Comparative results of the trials of the Northumberland, Welsh, and South Lancashire and Cheshire Coals.

	Economic value or lbs. of water evaporated from 212° by 1 lb. of coal.	Rate of combustion in lbs. of coal per square foot of fire-grate per hour.	Total evaporation in cubic feet per hour.	Area of fire-grate in square feet.	Rate of evaporation per square foot of fire-grate per hour in cubic feet of water from 212°.	Authority.
Northumberland	11·99	24·3	48·10	10·3	4·6	Admiralty Officers.
	12·58	17·25	66·85	19·25	3·5	Armstrong.
	10·66	37·4	98·7	15·5	6·4	,,
	11·99	28·9	57·48	10·3	5·6	Fletcher.
Welsh	12·47	20·8	43·23	10·3	4·2	Admiralty Officers.
	12·48	26·4	54·4	10·3	5·3	Fletcher.
Lancashire	11·6	27·0	52·8	10·3	5·1	,,
	11·96	27·0	54·09	10·3	5·25	Admiralty Officers.

these are more combustible or burn more "lively" than the best slightly-bituminous or best steam coals of South Wales, and are therefore superior in rapidity of combustion and evaporative velocity per foot of fire grate, or, in other words, can raise more steam in a given time. When speed of evaporation is a desideratum, the semi-bituminous coals have a decided advantage over their rivals. They are also about 50 per cent. harder to resist hammering and rough usage than the others, which, when broken by a hammer, splinter into fragments whilst the semi-bituminous coals merely break through their lines of cleavage.

These experiments prove that with care, semi-bituminous coals of good quality can be burnt without any smoke, and that their evaporative power is increased when the formation of smoke is properly prevented.

The results obtained in the experiments by dint of great

care and skill in firing and arranging the furnace for each kind of coal are considerably higher than are attained in ordinary work, and more especially in the case of the semi-bituminous coal, where the necessary attention required for economical smoke prevention cannot always be counted upon. The soot deposited from the flame of these coals soon forms a coating over the heating surface, which cannot be removed so frequently in actual work as during a series of experiments, and speedily impairs the steaming power of the boiler. Forcing the fires then becomes necessary, unless there be a large margin of boiler power, and both smoke prevention and evaporative economy become well-nigh impossible. The facility offered by good North country coals for rapid combustion tends greatly to cause carelessness on the part of the fireman, and it may be questioned whether their great combustibility is always an advantage, leading as it does to wasteful consumption; the required evaporation being maintained by "blazing away" the coals, instead of close attention to the stoking and keeping a well-spread and clean fire.

With the same description of boiler and furnace the heat of the escaping gases, when long-flaming semi-bituminous coals are burnt, is likely to be higher than when coals having a shorter flame are used. With the former the generation of the heat is spread over a greater length of surface by the long flame, and has consequently a shorter run for its absorption. In the latter case nearly all the heat at a very high temperature is generated on the bars, and can be taken up by the greater length of surface it has to traverse. For this reason shorter grates are required in burning semi-bituminous or long flaming coal than for a coal containing a less quantity of volatile ingredients, such as the South Wales steam coal, in order to obtain the same evaporative economy. This has been proved by numerous experiments, and also that the provisions for air admission and mode of firing best adapted for one kind of coal may be totally unfitted for another kind. The type of boiler and furnace should always be adapted to the kind and quality of coal to be employed. It is no exaggeration that boilers and furnaces can be selected which would give 50 per cent. higher duty with one kind of coal than with another, whilst in other boilers the superiority might be reversed.

In conducting competitive coal trials in any given locality the coal that has been carried the greatest distance is likely to be in the worst condition for testing. South Wales coal tested on

the Tyne is placed at a disadvantage with its rival, which can be procured fresh wrought from the pit, whilst at Cardiff the advantage would be on the other side. Owing, however, to the friable nature of the best Welsh steam coal, it deteriorates much more rapidly than its rival from the north, by shipment and transport, as well as by lying in store exposed to the atmosphere.

CHAPTER XIV.

SMOKE PREVENTION AND FIRING.

In considering the rationale of smoke making and prevention, it is advisable at the outset to explain what smoke really is, as there exists considerable misunderstanding on this point.

When a fresh charge of semi-bituminous coals, such as ordinary North country house coal is thrown on to the fire, in sufficient quantity to prevent the immediate formation of flame, a volume of gas or vapour usually of a dark yellow or brown, or bluish black colour, as seen against the dark background of the fire-place, is given off. The quantity evolved will be greatest when the coal is very small. This gas, or vapour, is commonly called smoke, but it is not what is meant by that term when used in speaking of the smoke-nuisance, and does not deposit soot. The colour of the gas as it issues from the chimney will greatly depend upon the character and distance of the background against which it is seen, upon the nature of the light it is seen by, whether it is transmitted or reflected, the former lending a yellowish, and the latter a bluish, tint.

Against a dark background of brickwork or hills, it appears grey or blue; against dark clouds, light brown or grey, or is not visible at all; and against white clouds or a blue sky, brown or yellow, but never quite black, or like true smoke.

If a sheet of white paper be held over the vapour as it escapes from the coal and there is no flame, the sheet will become slowly coated with a sticky matter of brown colour difficult to remove, and having a strong tarry or sulphurous smell. This colour and smell are due to the tarry matter, sulphur, and other volatile ingredients in the gas. Deprived of these colouring matters, the vapour is a carburetted hydrogen (chiefly olefiant gas, and marsh gas), or a chemical mixture of hydrogen and carbon, and nearly the same as the colourless gas by which our houses are lighted.

When the charge of coals and the escaping coloured gases

have attained a considerable temperature, the latter can be ignited on the application of a light or by stirring the fire. No coloured vapour will now be visible above the flame as seen against the back of the fireplace, but if we hold a clean sheet of paper above the flame, we shall find along with a greatly diminished amount of adhesive colouring matter a deposit of soft black smuts, or particles of carbon, different in colour and nature from the other deposit. A chemical change has taken place, one result of which is the appearance of these carbon particles which were not visible before. The carburetted hydrogen gas on becoming ignited is converted into flame, or in other words, by the aid of the heat the hydrogen of the gas has entered into chemical union with the oxygen of the air, producing flame and heat by their union and forming water, which passes off in invisible steam. At the same time, the carbon, which was present although invisible in the gas, has been liberated, and is partially consumed and partially deposited on the cold paper in minute visible particles.

In an open fireplace where the surrounding temperature is low the ignition of the hydrogen, and consequently the formation of flame is essential to the liberation of these carbonaceous particles which in their minute state are carried aloft by the ascending current of steam and gases, or are deposited as soot on the surfaces with which they come in contact. It is the volume of vapour and gases coloured by the carbon particles that forms smoke, properly so called. On issuing from the chimney these particles, if not carried away by their enveloping medium which is always of considerable volume (a ton of coal properly consumed giving off nearly half a ton of water), would fall at once as a cloud of light black dust. The colour of the smoke will be light or dark according to the proportion of carbon particles present in the gases.

The carbon contained in our lighting gas can be rendered visible, in a somewhat similar manner to the above, by pressing a cold white plate or saucer down upon a jet of burning gas. As the olefiant and marsh gases issue from the burner they are decomposed by the heat; the hydrogen is partially separated from the carbon, and being more inflammable, burns first with flame, in which the carbon particles are highly heated. If sufficient oxygen can come in contact with the carbon while still at a high temperature, it will be burnt without smoke, but by cooling it with the surface of the plate before the combination is effected, the carbon is deposited as very fine soot.

Smoke may be formed even with an abundant supply of oxygen at hand for combination with the carbon, by cooling down the flame below the temperature necessary for igniting the carbon, before the union is effected. This may be done by surrounding the flame with a good conductor of heat at a low temperature.

It would thus appear that the liberation of the carbonaceous particles, and consequently the appearance of true smoke takes place only after the formation of flame. This is true only so far as it applies to an open fireplace, or jet of lighting gas, where the temperature of the surrounding atmosphere is low.

In close furnaces where a high temperature is maintained, the carbon may be liberated from the gases by the heat without the combination of the hydrogen, and consequently without the presence of flame, smoke or soot being the possible result, as in the other case.

Smoke in all cases can be avoided simply by bringing a supply of fresh air in contact with the carbon while it is red hot in the flame, or at a sufficiently high temperature to combine with the oxygen. The combination passes off as invisible carbonic acid gas.

What is required then is the presence of sufficient air and a sufficiently high temperature. In our domestic fireplaces, we usually have the former, but as a very small quantity passes through the bars, the great bulk is of a very low temperature, and steals away the heat before the chemical union of the carbon and oxygen can be effected. In a boiler furnace, on the other hand, there is always a sufficiently high temperature, unless the furnace be choked with fresh fuel; but the supply of air, especially above the fuel, is too often wanting. The supply of air in sufficient quantity to the upper portion of the furnace, at the back, or front, or middle, or sides, is the object of all good plans for smoke prevention.

A mode of getting rid of the smoke by consuming it was formerly frequently, and still is to some extent resorted to without the direct introduction of air to the hot gases. The smoke once formed, is allowed to mix with carbonic acid at a high heat, a second furnace being sometimes provided for the purpose, when the solid particles of carbon are dissolved in the gas producing carbonic oxide. The result of this method is a considerable waste instead of a saving of fuel, although the appearance *of smoke* may be prevented. The plan might be

rendered economical by the introduction of a supply of fresh air at the right time and place.

As flame is essential to the production of smoke at a low surrounding temperature, it is evident that if the hydrocarbons can be expelled without flame, and the temperature at the same time kept down, there will be no smoke. In order to carry this into practice it is only necessary to dampen the coals sufficiently with water or to mix with them some substance, such as bark, containing moisture. The absorption of the heat by the fresh charge of coals and steam given off along with the gases as well as its interception by the caking of the coal which is increased by this treatment, keeps the upper portion of the furnace at so low a temperature, that the hydrocarbons escape in the unburnt state, without the formation of real smoke, but at a great sacrifice of fuel and speed of evaporation.

The prevention of smoke by this method is sometimes wrongly ascribed to the water introduced along with the coal, being decomposed by the heat, when the liberated oxygen is said to combine with the carbonaceous particles. But unfortunately for this theory, when the hydrocarbons do ignite, the presence of water seems rather to increase the quantity of smoke than diminish it.

As has been already observed, steam can be decomposed by passing it through a body of incandescent fuel, and the method is of service in some melting furnaces, but it is difficult to perçeive how any economical advantage is to be obtained by applying it to boiler furnaces (unless it is wanted for making flame), where it is also likely to reduce the firebars very rapidly.

Again, by regulating the draught, and by simply throwing on sufficient coal to choke and cool the furnace, the ignition of the hydrocarbons can be prevented, but as they pass off unconsumed, this method of smoke prevention is also very wasteful of fuel, besides having the disadvantage of making steam slowly and intermittently, especially when the coal is of a caking nature, since it cannot be stirred before the hydrocarbons have escaped.

Some plans to prevent smoke by closing the damper and so reducing the draught at the time of firing have been tried, and have always failed, except where the formation of flame has been prevented. The draught should be increased instead of diminished for a short time after firing, in order to give the most economical result.

ith a view to obviate the chilling influence of the boiler

plates, which extinguish the flame coming in contact with them before the combustion of the carbon particles is completed, various plans have been tried for completing the combustion in fire brick reverberatory furnaces erected in front of the boiler.

In furnaces of this kind there is often a greater loss of heat by radiation and conduction than in a furnace either inside of or directly underneath the boiler, and the extra cost involved in their erection and maintenance not being compensated by any corresponding saving in fuel, operates against their general adoption. This plan of delaying the utilisation of the heat until the combustion is complete is no doubt theoretically correct, but most attempts to carry it out in practice have failed in economy, probably owing to the loss of the radiant heat from the incandescent fuel.

FIRING.

The thickness of the fire and its mode of distribution on the grate must be regulated by the size, quality, and nature of the fuel, the force of the draught and the facilities for effective air admission. When coke and good-sized coals, containing a small proportion of hydrocarbons are used, sufficient air for perfect combustion can be made to pass through the fire bars with a good draught, provided that the fire, generally speaking, does not exceed 8″ in thickness. With a forced draught, as in locomotive boilers, this thickness may be greatly increased, but it is dependent in a great measure upon the size of the pieces and character of the fuel.

By careful firing, and admitting a sufficient quantity of fresh air directly to the hydrocarbons, nearly any kind of semi-bituminous steam coal can be burnt without smoke.

In using round semi-bituminous non-caking coal of the best quality, a fire in ordinary sized furnaces from 10″ to 14″ thick is the best for economical combustion, care being taken that sufficient, but not too much, air is admitted for admixture with the combustible gases whilst they are still at a very high temperature. The best mode of firing most kinds of good smoky coal of this description is to pile it up on the dead plate, in order to allow the volatile ingredients to be expelled by the heat radiated and diffused through the furnace. These ingredients, mixing with an adequate supply of air entering through the provisions in the furnace door or front, ignite in passing over the hot fuel, and are completely consumed.

The mass piled up at the door becomes gradually converted into coke, and on being pushed forward over the fire at the next charge is burnt principally by the air which passes through the bars. Some furnaces require to be altered for the successful carrying out of this "coking" method of firing, which gives the most economical, though not the most rapid evaporation. The pieces of coal should not be introduced larger than the size of a man's fist. The fire will require recharging every 20 or 30 minutes, according to the draught, combustibility of the coal, and size of furnace.

If the coal is small and cakes very much, this plan is not admissible, and regular firing with moderate charges at from 10 to 15 minutes' intervals must be adopted. With two furnaces, it is best to fire alternately, and not one immediately after the other, in order to maintain as much as possible a steady evaporation, and to prevent a double volume of smoke appearing in case any should be produced. When the width of the furnace permits, it is also advisable in most cases to employ "side" firing, that is, to throw the coal on each side of the fire alternately, always leaving one side bright, so as not to cool the whole furnace at once. This method is preferable to the "spreading" system which is commonly employed. There can be no doubt that this last is the best mode of firing for rapid evaporation, but it is the least economical and the most difficult for avoiding smoke making, unless very small charges at short intervals are introduced.

The number of shovelfuls thrown on at each charge with both side firing and spreading firing will vary from 4 to 12, according to the size and quality of fuel, intensity of draught, and speed of evaporation required.

In using small coals—slack, duff, pease, or beans, the gases are disengaged almost instantaneously when a charge is thrown on to a hot fire, and cause a difficulty of admixture with the air, even when a sufficient supply is present. The only way to prevent smoke when using slack, without wetting it, is to keep up an almost continuous firing with small charges in order to aid the mixing of air with the gases. With limited boiler power, however, this method cannot be successfully employed, as the cooling effect of the large and frequent volume of cold air entering through the open furnace door checks the quick raising of steam, and even where the boiler power allows of this plan being carried out, the volume of air which passes unburnt is far too large to render the employment of such a

method consistent with a due regard for the economy of fuel.

For the most economical method of burning slack without producing smoke, mechanical firing must be resorted to. This enables a small and regular supply of fuel to be introduced without the admission of too much air ; in fact, the supply of air may by more than one method of mechanical firing be too much restricted, and cause a waste of heat by the production of carbonic oxide. This is, however, seldom the case and the error of having too thin and open a fire, which allows too much air to pass off unburnt, is the rule.

The steady evaporation ensured by a good arrangement of mechanical firing is sometimes a serious objection to its employment, where the quantity of steam required varies quickly and to a considerable amount. Another objection urged against most systems of mechanical firing is that the speed of evaporation is inferior to hand firing. This can in most cases be obviated by altering the rate of feeding, thickness of fire, and details of furnace.

With good round coal, hand firing is preferable to any description of mechanical firing, with respect to both rapidity and economy of evaporation, whilst very little skill is required for a satisfactory prevention of smoke when there is sufficient boiler power.

The size of the perforations for the admission of air through the furnace front should not exceed $\frac{1}{2}''$ diameter, and the sum of their areas should not be less than $2''$ per square foot of fire grate, and in some cases requires to be as much as $5''$ per square foot of grate surface.

Perforated dead-plates are sometimes used with advantage, and in many cases when the supply entering by the perforations is not sufficient for consuming the smoke, the furnace door may be left ajar for a minute or two after firing.

As to whether the admission of air above the fire requires to be regulated for the different stages of combustion, there is a diversity of opinion. It is contended that as the largest amount is required when the gases are evolved immediately after firing, the quantity admitted, when constant, must be too great for the last stages of combustion if merely sufficient for the first, and a loss of heat must be the result. This argument applies with greatest force to the spreading system, where the requisite quantity of air after charging is greatest, and where the escape of the gases is soonest completed. But when the coking system

is employed the evolution of the hydrocarbons is more gradual and continues for some length of time, during the whole of which the admission of air is necessary. Experiments, recorded by Peclet, on a boiler with provisions for admitting air above the fuel, having an area of ·16 the air space of the fire grate, showed that the quantity introduced through the bars immediately after each charge was very small; that the quantity increased as the coal became converted into coke, and at the end of the interval between firing it was about four times as great as at the beginning. The quantity of air admitted by the openings above the fuel remained nearly constant.

These results distinctly show that with any but the coking system of firing, the air admission above the fuel should only last until the hydrocarbons are expelled, that is, two or three minutes after firing.

With a constant admission of air to the upper part of the furnace, even on the coking principle, the speed of evaporation is usually diminished, although smoke is prevented. This is why so many engineers and firemen object to the plan of admitting air above the fire.

The difficulty caused by the diminution in the speed of evaporation points to the greatest obstacle economical smoke-preventors have to contend with, namely, the want of sufficient boiler power. There are many boilers worked so hard that the admission of air above the fuel in barely sufficient quantity to prevent smoke, reduces the rate of evaporation below that required. Boilers working under such conditions are burning their fuel with a great waste, and although the evaporation may be rapid it is at a sacrifice of economy. On the other hand, the fact of the necessity of having so much boiler power, shows that the cooling effect of admitting a considerable quantity to prevent smoke may not always be economical.

The fact is, that in many cases no economical gain has been obtained by a complete smoke-prevention but just the reverse. This may be accounted for on the supposition that the increase of heat due to the burning of the hydrocarbons is sometimes counterbalanced by the lowering of the temperature by the excess of air after the fuel is converted into coke, or that there is an excessive admission of air when the hydrocarbons are evolved, or that the facilities for mixing the air with the gases at the right time and place are insufficient. Peclet records some experiments where it was found that so long as there was a larger volume of carbonic acid than free oxygen in the escaping cur-

rent, the smoke was thick; that it began to clear when the two volumes were equal, and disappeared when the volume of free oxygen was equal to twice that of the carbonic acid.

It is frequently found necessary to shorten the fire grate in order to maintain the evaporative economy, when a furnace is altered with a view to prevent smoke by admitting air directly to the gases evolved from the coal. In very many boilers the length of fire grate is excessive. Whenever it exceeds 6 feet it is almost certain to be productive of waste, as the grate beyond this length is beyond the control of the stoker in the majority of furnaces. Indeed, there are thousands of boilers working with 6-foot grates, which might with great advantage be reduced by from 12 to 24 inches in length. A large grate by burning more fuel will raise more steam in a given time than a smaller grate, but the increase of evaporation will not be proportionate to the increased quantity of fuel consumed. The shorter the grate the more economical will be the consumption. In fact, the economical limit to shortening the grate is only fixed by the power of producing sufficient steam without burning the coal too rapidly for complete combustion, by distressing the fire with too frequent stirring.

Cases are to be found where the difficulty of keeping a very large grate covered increases so rapidly with the strength of the draught, that the production of steam is actually reduced as the draught is increased, in spite of the greater consumption of fuel. This is owing to the quantity of unburnt air, which passes through one portion of the grate, increasing more rapidly than the quantity of heat generated on the rest of the grate. In such cases a reduction of the size of the grate, or force of the draught, will be followed both by speed and economy of evaporation, and less attention will be required in firing.

The bars of internally fired boilers are frequently placed too high, the advantages of a large combustion space to aid the mixing of the air with the hydrocarbons, of a large furnace surface for absorbing the radiant heat from the fuel, and of a thick fire for burning all kinds of good steam coal, being too frequently sacrificed for the single advantage of an inch or two more width of grate.

The distance of the bars from the bottom of externally fired boilers may be varied within considerable limits, according to the size of boiler, intensity of draught, nature of coal, and thickness of fire. A distance of 14″ or 16″ from the surface of the fire *to the boiler* plates appears to be about the best average

height. By increasing the distance much of the effect of the radiant heat is lost, and by bringing the fire too near the boiler there is a liability of damaging the plates, and of extinguishing the flame, impairing the combustion, and producing smoke.

The weight of fuel in pounds per hour burnt on each square foot of grate is termed the rate of combustion, and depends upon the draught and combustibility of the fuel. The rate of combustion varies with different classes of boilers, and in different districts. The following may be taken as the average practice with semi-bituminous coals.

	lbs. per square foot of grate per hour.
Lowest rate of combustion in Cornish boilers	4
Usual rate in Cornish boilers . . .	10
Usual rate in externally fired and internally fired Factory boilers	10 to 18
Usual rate in Marine boilers . . .	14 to 26
,, ,, in Locomotive boilers, with blast pipe	60 to 130

The maximum rate of combustion of semi-bituminous steam coal, with air-admission through the grate and above the fire and with chimney draught, is about 40 lbs., but the evaporative economy decreases rapidly with a combustion exceeding 30lbs. The maximum rate of slightly-bituminous steam coal with air-admission through the grate only is about 35 lbs., but even below this rate the intense heat given out by these coals has been found to fuse the bars rapidly. Their evaporative economy decreases with a more rapid rate of combustion than 26 lbs.

CHAPTER XV.

HEATING SURFACE.

The evaporative power of a boiler mainly depends upon the efficiency of its heating surface, whose duty is to transfer the heat from the products of combustion without to the water within.

The heat is communicated to the transmitting surface in two different ways,—by radiation and by contact; and from two or three different hot masses in the furnace, viz., the solid incandescent fuel, the flame, and the hot gases produced by combustion. Beyond the furnace bridge or tube plate the heat is imparted by contact and radiation from the flame and gases only.

The amount of heat transmitted by radiation from one body to another diminishes as the square of the distance between the bodies increases. The effect on any surface is also diminished by any increase in the inclination at which the rays fall upon it.

The radiation from solid incandescent fuel is greater than from flame, whilst transparent hot gases scarcely radiate any heat at all. The more intense the contact heat of the flame by thorough mixture with the air, the less is the heat by radiation..

Conduction is the transfer of heat either between the particles of the same body, or between the parts of different bodies in contact, and it is distinguished respectively as internal and external conduction. The rate at which the former takes place in metal plates is very much greater than the latter, where the heat passes from the hot mass to the plates, and from these again to the water.

The efficiency of any heating surface may be defined as the proportion borne by the amount of heat it transmits to the whole amount available for transmission, and in this sense the term efficiency will be here used. The conditions on which this efficiency depends are as follows :—

1. The extent of surface acted upon by the heat and in contact with the water.

2. Its position and arrangement with respect to the heating medium on one side and the water on the other.

3. The nature, condition, and thickness of the solid body forming the heating surface.

4. The difference of temperature between the heat on one side of the solid body and the water and steam on the other.

5. The time allowed for the transmission of heat.

6. The nature of the heating medium, and the manner in which the heat is communicated, whether from incandescent fuel, flame, or heated gas, and whether the heat is communicated by radiation or by contact.

1. In estimating the extent of heating surface it is customary to take the whole area of furnace, combustion chamber, flues, water tubes, &c., in contact with the heat on one side and the water and steam on the other, and to consider the evaporative power of the boiler as proportional to the total number of square feet of surface thus found. It is evident this method would be correct if every unit of heating surface possessed the same transmitting value. As we shall presently see, however, this is not the case, and although the efficiency of the surface may be increased by extending it, it does not follow that the increase of efficiency is in direct proportion to the increase of extent, but is greatly dependent upon the other conditions enumerated.

2. Owing to the low conducting power of water the application of heat to its upper surface is almost entirely useless for warming the mass of water beneath. Inflammable liquids floating on water can be burnt without raising it 1° in temperature, whilst generating sufficient heat to evaporate the whole mass if applied below instead of above.

In order to obtain the greatest effect the heat should be applied to the bottom of a vessel containing water, and when the heating medium is inside a vessel surrounded by water it should be applied to the crown. In both cases the heat is diffused through the liquid mass by convection. When water is heated it becomes lighter and ascends, being displaced by a descending column of colder water; but when the water is heated by the bottom of a vessel or tube with which it is in contact, on becoming lighter it clings to the surface above it, and diffuses no heat downwards.

In Tredgold's work on the steam engine it is recorded:—"*Mr. Armstrong* found that a cubical metallic box, submerged

in water, and heated from within, generated steam from its upper surface more than twice as fast per unit of area than it did from the sides when vertical, and that the bottom yielded none at all. These remarkable differences are owing to the difficulty with which steam separates from a vertical surface to give place to fresh charges of water, and to the impossibility of leaving the inverted surface at all. By slightly inclining the box the elevated side much more easily parted with the steam, and the rate of evaporation was increased; while on the depressed side the steam hung so sluggishly as to lead to an overheating of the metal."

A flat horizontal surface not too far above the layer of fuel is usually considered to be the most favourable for raising steam. By being made concave to the fire it has, however, the further advantages of being still better adapted for receiving the radiant heat; of facilitating the access of fresh supplies of water to replace the heated ascending particles, and thereby promoting the circulation; of boiling off the matters deposited from the water, and so preventing incrustation; and of being stronger, and in some cases more durable.

Next in efficiency to the flat surface with the water above comes the sloping surface surrounding the fire, which is superior to one in a vertical position, as it receives the rays of heat at a more favourable angle, and allows the steam bubbles to escape more freely. The sides of locomotive fire boxes for these reasons, as well as for improving the size of the usually too contracted water spaces, are best made sloping, although the area of the crown is thereby somewhat diminished.

In the locomotive class of boilers the fire box tube plate acts perhaps as effectively as the crown in transmitting the heat per unit of area, the rapid impingement of the flame and hot gases against it compensating for any disadvantage due to its vertical position. The efficiency of the crown is too often impaired by its top hamper, in the shape of stays, ferrules, bolts, &c.

From what has already been stated it is obvious that the value of any horizontal surface beneath the fire, whether flat or curved, is inappreciable, and not worth consideration as heating surface. In externally fired boilers the heating surface is usually convex to the fire. This is by many regarded as inferior to a conçave surface, probably because it is not so well adapted for directly receiving the radiant heat from the fire, and does not appear to offer an equal facility for circulation. The results obtained from this description of surface in actual work

do not appear to verify this conclusion. The inferior evaporative power usually alleged of the ordinary externally fired boiler is, in great measure, due to the dissipation of heat in the furnace.

Where the containing vessel is surrounded by the heating medium, as in water tube boilers, and in the "bouilleurs" of elephant boilers, the top side cannot be considered as effective heating surface, in consequence of the manner in which the steam remains in contact with it. The efficiency of these tubes surrounded by heat should increase rapidly with the pressure, since the space occupied by the steam will decrease as the pressure is augmented, and the circulation will be improved. The sides hold an intermediate position between the top and bottom, which latter may be taken as completely effective in absorbing and transmitting the heat. Taking the efficiency of the top as 0, and that of the bottom as 1, that of each of the two sides will consequently be $\frac{1}{2}$, and the average of the whole circumference

$$\frac{0 + \frac{1}{2} + \frac{1}{2} + 1}{4} = \frac{1}{2}$$

showing that the whole surface utilises only one half the quantity of heat it would utilise if it were all equally as effective as the bottom. In like manner the effective area of a tube internally heated will be found to be only one-half its total area. In plain cylindrical externally fired boilers only the under half of the circumference is exposed to the heat, whilst in an internally fired tubular boiler the whole surface of the tube beyond the bridge (when clean) is exposed. If we take the ratio of the diameter of the externally heated boiler and internally heated tube as 2 : 1, the whole surface exposed will be equal in both for a given length of boiler, but the effective surface will be in the ratio of 3 : 2 in favour of the externally fired boiler.

On leaving the furnace the flame and hot gases come in contact with heating surface, which may consist of internal tubes of widely different sizes, and of elliptical, circular, or rectangular cross section; combustion chambers; horizontal, inclined, or vertical water tubes; and the flat or round ends and curved bottoms and sides of the boiler shell. As we have already seen, the upper portion of horizontal internal *tubes forms* the most effective evaporating surface, the flame

and hottest portions of the gases coming in contact with it on one side, and the steam escaping readily from the other. The upper surface of the tube on the fire side is kept tolerably clean by the intense heat and current of hot air when the draught is not sluggish. The water side is kept comparatively free of incrustation when the deposited matters carried up by the ebullition are not prevented from passing away and settling where the water is quiet. For this reason, and also to allow the rising steam to escape freely, sufficient space should be left between the tubes in a multitubular boiler,—about $\frac{1}{3}$ their diameter. For facility of cleaning or washing out, and also to facilitate the escape of the steam as it is generated, a cluster of small horizontal tubes are best arranged in vertical rows, and not zig-zag, or in rows running at an angle of 30° or 60°, which is done for the sake of getting the greatest possible number of tubes in a given area of tube plate.

The crowding of tubes in multitubular boilers is often carried to an extreme, especially in the locomotives on some of the Continental railways, with the view of getting more surface, but without regarding the other conditions of steam raising. Heating surface in the abstract is one thing, its efficiency is another. Theoretically, the spaces between the tubes should increase with the distance from the lowest row of tubes. In arranging them in vertical rows this can only be attained by decreasing the diameter of the tubes as they ascend, which is, however, objectionable in practice. The under portions of the tubes and internal flues are almost worthless for steam raising, not only on account of the difficulty the steam has in escaping from the surface on one side, but also in consequence of the deposit of soot, ashes, and flue dirt which is the rule on the other. The incrustation also accumulates much more rapidly, and to a greater thickness, on the under side than on the crown of tubes, especially of large diameter, principally on account of the comparatively quiescent state of the water in contact with the former.

The manner in which the heat from the swift current through a horizontal tube is brought in contact with the metal is probably by a kind of convection. Assuming the gases entering a tube to be all of the same temperature, the particles striking against the upper surface must give up part of their heat, and in cooling descend by virtue of their increased gravity, despite the onward and upward force due to the momentum of the mass which opposes their descent. The hot particles immediately

behind and beneath these will come in contact with the upper surface a little further on, and so a species of convection is kept up as the gases sweep along. This probably gives rise to the undulating and winding manner in which flame may be observed to pass along a horizontal tube. It would hence appear that the tubes should be inclined downwards from the furnace, instead of being quite horizontal, in order to aid the contact of the hot gases with their upper surfaces. A very small amount of heat is transmitted by radiation from the hot gases during their flight. But when the flue deposit on the bottom of small tubes is not too thick to impair the draught it may act advantageously in robbing the lower part of the gases of part of their heat, which, when sufficient to maintain the layer in a state of incandescence, will be imparted by radiation to the tube crown.

In horizontal internal flue tubes various means have been devised for extracting more of the heat out of the gases than they will yield by radiation or conduction through their mass, by breaking the currents at intervals, and so bringing fresh portions of the gases in contact with the plates. This is perhaps best effected in large tubes by the introduction of side water pockets and central water tubes, which also improve the circulation, and at the same time may be made to impart additional strength to the main tubes. The area of the passage is, however, contracted by these expedients, and the draught impaired, which in some cases causes a reduction in the evaporative velocity, instead of an increase, which the application of the increased heating surface is expected to produce. The cleaning of even large tubes is rendered more difficult by these heat extractors, which circumstance alone very often more than counteracts any advantage they would otherwise afford, causing a reduction both in the economy and rapidity of evaporation. This difficulty precludes their adoption in small tubes altogether. Only the face of the water tubes and pockets against which the rapid current impinges on its way to the chimney can be regarded as really effective heating surface. In order to facilitate the escape of the steam as it is generated, vertical water tubes should be made conical, and no water tube should ever be arranged horizontally, as this position is unfavourable to the circulation, and renders the escape of the steam well nigh impossible.

In passing up through vertical tubes the gases act at a disadvantage for imparting their heat to the plates. The particles

cooled by contact with the sides on entering have no tendency to make way for those in the middle of the current that still retain their heat, which can therefore only be indifferently imparted by radiation or conduction. Transverse water tubes, or some other means for extracting the heat from the gases by contact are necessary adjuncts to vertical boilers, to render them anything like economical steam generators. These water tubes should always be arranged with considerable inclination, to allow the steam to escape freely along the upper surface, against which it rises as quickly as it is generated at the bottom, and so improve the circulation. The cross tubes both in vertical and horizontal internal flued boilers should never be arranged all in a line, but each tube should be set at an angle with those preceding it, so as to intercept the greatest possible amount of heat by breaking up the current of hot gases.

Besides greatly adding to the heating surface, the cross tubes and the auxiliary vertical tubes sometimes used in upright boilers also promote the circulation throughout the boiler, and thus act indirectly in improving the heating surface of the main tubes themselves.

3. The evaporative efficiency depends on the nature, condition, and thickness of the material forming the heating surface. In a homogeneous plate the resistance to internal conduction is proportional directly to the distance the heat has to traverse, or to the thickness of the plate and inversely to the difference of temperatures between the two faces, whence the quantity of heat in units transmitted, through 1 square foot of plate per hour may be represented by

$$Q = \frac{T - T'}{Pt}$$

where T = temperature of hot gases; T′ = temperature of water; t = thickness of plate in inches; and P = co-efficient of thermal resistance found by experiment, and, according to Peclet, is ·0096 for iron and ·0040 for copper.

Expressing the resistance to external conduction by the co-efficients, H and W, which represent respectively the resistance to the absorption of heat by the face of the plate, and the resistance to emission on the other side in contact with the water, then the total thermal resistance, internal and external,

is expressed by $P\,t + H + W$ and the quantity of heat transmitted by

$$Q = \frac{T - T'}{P\,t + H + W}.$$

From this expresion it is evident that the heat transmitting power of the plate decreases with the thickness and resistance, or conversely, increases with the facility offered by its heat-absorbing, conducting, and emitting qualities; also that the resistance is not directly proportional to the thickness or the conducting power of the plate. The smaller P and t and the larger H and W become, so does the importance of the influence of the thickness diminish. In consequence of the great superiority of the internal compared with the external conduction of copper, brass, iron, and steel, some eminent authorities conclude that the small difference in their conducting powers and thickness has no appreciable influence on the amount of heat they transmit.

Peclet, who found that all metals conduct about alike, when their surfaces are dull, quotes two experiments that appear to bear out this conclusion. One was with a boiler of cast-iron and the other with a boiler of copper. Both were exposed to a fierce fire and plunged into the flame. Each produced about 20 lbs. of steam per square foot of surface per hour.

Carefully conducted experiments, and the result of actual practice, show that after the first few days' work, with ordinary impure feed water, there is no perceptible difference in the evaporative power of copper, brass, and iron tubes, although their relative internal conduction powers are respectively 74, 24, 12, and that so far as the economical use of fuel is concerned, there is no gain in employing the dearer metals. The same result has also been found when using slightly different thicknesses of the same metal. Although the difference between the steaming powers of new boilers with furnace plates $\frac{1}{2}$ and $\frac{3}{8}$ inch thick is sometimes found to be material, it rapidly disappears as the plates become coated over on both sides. Layers of oxide, incrustation and grease on one side, and soot, flue deposit, or the products from the slow distillation of the coals on the other, greatly increase the resistance to the passage of the heat. The conductive powers of these substances really measure the evaporative power of the tube or plate; *being* bad thermal conductors, their obstruction to the passage

of the heat from the gases or fuel to the water is so great, in comparison with that of iron or copper of ordinary thicknesses, that the latter loses its significance, or, in other words, the quantities P and t, for either copper or iron in the formula are so small, compared with H and W, as not to be worth considering.

The rapidity of the internal conduction is greatly dependent upon the homogeneity and solidity of the plates, for all kinds of boiler materials. Where much lamination occurs in the plates, the internal may actually become a succession of external conductions, the rate of transmission being in consequence seriously affected. It is a well-known fact that $\frac{1}{2}''$ and $\frac{9}{16}''$ furnace plates are much more liable to fracture and become otherwise injured from excessive heating than $\frac{5}{16}''$ and $\frac{3}{8}''$ plates. This is sometimes adduced as a proof of the inferior evaporating powers of thick plates; but it does not follow that the inferiority is appreciable in the amount of water evaporated. The manner in which the injury to thick plates comes about is as follows—when the plate is homogeneous and uniform, the conduction between the two faces will be uniform throughout, the temperature being highest on the fire side and diminishing gradually to the other side, where it is lowest. The difference will be in proportion to the thickness. Assuming the face in contact with the water to be maintained at a constant temperature, it follows that the other face will be more and more heated as the thickness is increased, and consequently more liable to injury from sudden cooling. If the internal face, instead of being in contact with water, is covered with scale, or the plate is laminated, or a double thickness occurs, the thermal resistance may be indefinitely increased, and the liability to injury by the plate attaining a very high temperature seriously aggravated. This is proved by the bursting of blisters and the fracturing of the lap edges through the rivet holes. Formerly, when the difficulty of rolling-boiler plates increased with their thickness, the more frequent presence of lamination in thick plates would probably have much to do with their alleged increased resistance to thermal conduction. The difficulty of obtaining sound boiler plates $\frac{3}{4}''$ thick, and even more, is, however, no longer to be considered general.

It is said that the thickness of the wrought-iron fire box plates in American locomotive boilers is diminished gradually, by the *action of the heat*, until they are about $\frac{5}{16}''$, which

appears to be the thickness that transmits the heat with just sufficient rapidity to keep the surface on the fire side below a wasting temperature. This wasting does not take place to so great a degree with copper plates, owing to its superior internal rate of conduction, $\frac{7}{16}$ inch being the thickness which corresponds in this respect to the $\frac{5}{16}$ inch iron. It is obvious, however, that the impurities in the fuel and water and local action of the draught will affect the thickness of the plate, quite independently of its conducting power.

It is the opinion of some experienced boiler inspectors that thick furnace plates, both vertical and horizontal, receive a slightly thicker coating of incrustation than thin plates, under exactly similar conditions of temperature, water, &c. This can only be accounted for on the supposition that the ebullition over the thicker plates is less intense, which would appear to prove their inferior evaporative value.

4. In coming in contact with the first unit's length of heating surface the gases part with a portion of their heat, they will consequently have a diminished amount for the next unit's length, and this will be still further reduced by contact with fresh surfaces, so that each successive portion transmits a gradually diminishing quantity of heat, until the gases escape with a certain excess of temperature above that of the water. It is usually stated that the quantity of heat so transmitted by the plate or tube is in direct proportion to the difference in temperature between the heating medium on one side and the water on the other. This conclusion must, however, be received with some qualification. If the hot gases and air passing through a tube possessed the property of imparting their diminishing heat, under similar conditions and in a uniform manner throughout, and if the resistance to conduction offered by the heating surface were uniform for its entire length, it is probable that the heat imparted at each point in its passage would be nearly in direct proportion to the difference of temperature. Assuming the gas to enter the tube at 1800° and at each successive stage to impart $\frac{1}{6}$ of the difference of temperature to the water at 212°, we should have the first amount transmitted

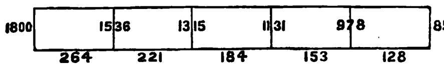
$$\frac{1800^\circ - 212^\circ}{6} = 264^\circ.$$

The gas arrives at the next point with a temperature of $1800^\circ - 264^\circ = 1536^\circ$, the amount utilised in this case will be

$$\frac{1536^\circ - 212^\circ}{6} = 221^\circ.$$

The temperature at the next stage will be $1536^\circ - 221^\circ = 1315^\circ$, and so on, for each successive steps, until the gases escape at 850°, as shown in fig. 23.

Fig. 23.



But the manner in which the heat is transmitted by the gases is not the same throughout. At that end of the tube where they enter the heat is imparted to the metal directly by the hot gases in contact, which are thereby rapidly cooled down, and the heat for the remaining length of tube must, in some measure, be transmitted by radiation or conduction from the hotter particles, at the axis of the tube, through the cooler mass, which now surrounds them, or by convection, as stated at page 277. As the transmission of heat by radiation and conduction requires time, and is almost nil with hot air and transparent hot gases, it appears then that the heat near the exit end must be imparted mainly by convection, and, therefore, at a comparative disadvantage, and hence the evaporative duty of opposite ends of the tube will not be in direct proportion to the difference between the temperatures. The amount of heat imparted as the gases are cooled down will not be so great as we obtained above, nor will the temperature of the escaping gases be so low.

If this be the case when air is the heating medium throughout, the difference in the proportion of the quantity of heat imparted at opposite ends will be much greater when flame is drawn through a tube or along the bottom of a boiler, for a short distance, owing to the great superiority that flame possesses over hot air as a heating agent under the circumstances we are considering.

According to Professor Rankine, when the difference between the heat of the gases and the water is very great, the rate of conduction increases faster than the simple ratio of that difference, and is nearly proportional to the square of the difference of temperature. The rate of conduction in thermal units for plates and tubes per square foot of surface per hour may be expressed by

$$Q = \frac{(T - T')^2}{a},$$

where T and T′ represent the temperatures of the two fluids, which are respectively in contact with the two faces, and a is a constant, which, lying between 160 and 200, agrees very well with the results of experiments on the evaporative power of boilers.

The above considerations will lead us to expect a very small evaporative duty from the exit end of long tubes, or, generally, from heating surface where the temperature of the gases is very much reduced, or the heating medium is changed from flame to heated air and steam, and no surprise will be caused by the results of various experiments that have been made from time to time, to prove the superiority of firebox surface to tube surface. In 1830 Stephenson found that in a locomotive boiler, open to the atmosphere, and with the firebox separated by a plate from the barrel, that one foot of firebox was equivalent to three of tube surface. In 1840 Mr. Dewrance modified the experiments by dividing the barrel of a small locomotive boiler into six compartments, that next the firebox being 6″ long, and the remaining five compartments each 12″ long. The results found were that the first six inches of tube were equal, area for area, to the firebox surface; the second compartment was only about one-third as effective, while in the remaining four compartments the evaporation was so small, according to the experiments, as to be practically useless.

In 1858 Mr. C. W. Williams experimented on a small open-topped boiler, 4′ 6″ long, having a 3″ tube passing through it. The boiler was divided into five compartments, the first being 6″ and the rest 12″ in length. The heat was supplied by means of a gas burner, placed in one end of the tube, bent down at a right angle. In a trial of four hours the water evaporated from 44° was in the five compartments severally 96, 44, 24, 19, and 16 ounces; and although the temperature of the escaping products of combustion was about 500°, that of the water in the last compartment was only 170°. In another trial of four hours with the same boiler, from an initial temperature of about 190°, the results were 98, 44, 32, 23, and 17 ounces evaporated. The temperature of the water in the last compartment fell to 170°, showing *that* the absorption was less than the radiation of heat, which,

however, would not have been the case had the boiler been closed in or protected.

The temperature of the escaping products was in this case about 485°. In a third experiment the boiler and tube were lengthened to 5′ 0″, and divided into five equal compartments, 12″ long, and a strong coke fire was substituted for the gas jet. In a trial of three hours the quantities evaporated from 50° were 117, 92, 73, 64, and 63 ounces, the products escaping at a temperature of 800°, whilst the temperature of the water in the last division did not exceed 206° at the conclusion of the trial.

About 1864 some further trials were undertaken with a multitubular boiler 5 feet long. The tubes were divided off into 6 lengths by plates at intervals. The compartment next to the tube plate was only 1″ long, the second 10″, and the four remaining were 12″ in length each. The following quantities of water were found to have been evaporated, after three hours' work :—

Compartment	No. 1	(1″ long)	— 46	ounces.
,,	,, 2	(10″ ,,)	— 47	,,
,,	,, 3	(12″ ,,)	— 30	,,
,,	,, 4	(12″ ,,)	— 22	,,
,,	,, 5	(12″ ,,)	— 18	,,
,,	,, 6	(12″ ,,)	— 17	,,

As there were no separate means of measuring the quantity evaporated by the tube plate, the large amount given for the first length of 1″ was in reality partially due to tube plate surface. The decreasing value of each succeeding length need occasion no surprise, although the exact manner of decrease in each case is not very clear.

From these and other experiments it has by many been erroneously concluded that in boilers having long tubes, say 10 feet or more, only the first 12″ or 20″ of length is of material evaporative value. The results of the experiments were however obtained under conditions very different from those under which the tube is employed in practice, the principal difference being the absence of the strong draught which draws the flame through the tubes, especially in a locomotive boiler. The stronger the draught the greater will be the temperature of the escaping gases, and consequently the greater the waste, but by pulling the flame through the tube the value of the heating

surface is more equalised for the whole length and the rapidity of evaporation greatly increased. The stronger the draught the greater the velocity of the current of gases, and as we shall presently see, the greater should be the length of the tubes to allow time for absorbing the heat. Experience proves that in boilers at work all the tube surface is important for speed of evaporation, provided the draught is suitably increased with the length of tube.

The great superiority of the furnace-heating surface, both in locomotive and other types of boilers, is no doubt greatly owing to the radiant heat from the incandescent fuel being principally absorbed here. According to Peclet, the proportion of radiant heat from red-hot coal may be taken as 0·5 of the total heat of combustion. The greatest quantity of this is given out upwards, and but very little is absorbed by the hot air, except what is not taken up by the plates against which it radiates, in the same manner as our atmosphere is only warmed by the earth and not by the sun's rays which pass through it.

If we assume that $\frac{3}{8}$ of the total heat from the incandescent fuel is absorbed by the furnace plates, and $\frac{1}{4}$ is carried off by the escaping gases for producing the draught, we have only $\frac{3}{8}$ left for absorption by the heating surface of the flues or tubes, and owing to the heat being more favourably circumstanced for absorption by the surface near the furnace there remains but little heat to be extracted by the surface at a distance from the fire. The tube surface is of most value for transmitting the heat from the flame which comes in contact with it, and its value is least when the fuel burns without flame.

The comparatively small heating power at the escaping ends of the tube in the experiments is only what we might expect when the hottest portions of the gases are not brought into direct contact with the plates. There are many cases where the tube surface has been replaced by combustion chambers, presenting a less amount of transmitting area for the flame, but allowing a better mixture of the gases and a more perfect combustion, yet a loss of evaporative power has generally been the result, showing that the value of the tube surface had been underrated.

On the other hand, increasing the heating surface by placing numerous tubes at the back end of long internally fired boilers has led to disappointment, no benefit having resulted from it, in great measure owing to the reluctance with which the hot

gases give up their heat, and in consequence of the retarding of the draught by the contracted area of the tubes. There is also another important circumstance that operates strongly against the evaporative power of the back ends of long tubular boilers of all classes where bad feed water is used, except, perhaps, in locomotives. The parts of the boiler on which the incrustation is most thickly and rapidly deposited is where the water is quietest, or the ebullition least violent, and consequently where the least amount of heat is absorbed. This amount of incrustation increases with the age of the boiler, and as the resistance to thermal conduction increases in proportion, it is obvious that the rate of conduction will decrease in a still more rapid ratio than the square of the difference in temperature between the two faces. In many cases of externally and internally fired boilers, the decrease in the rate of conduction and evaporation cannot be less than the cube of that difference.

It is evident from what has already been stated that we must at last arrive at a point where no useful effect can be gained by still further increasing the heating surface. This point is not always determined alone by the difference of temperature between the two fluids, which at any point depends in great measure upon the force of the draught, but is governed also by the nature of the heating medium, position of heating surface and its resistance to conduction. Where there is no means of improving the draught there is a positive loss in having too extended a heating surface, either in plates or tubes, especially in the latter, as the accumulation of soot that takes place in them impedes the draught, which again causes a further deposit of soot, and so the evil goes on increasing.

If we assume the diminution of the rate of conduction we found at page 283 to be correct, at the same rate, by doubling the length of the tube we should have the temperature of the escaping gases at 474°, giving an increase of 376° utilised for evaporation or

$$\frac{376}{1800-212} = 24 \text{ per cent.}$$

of the available amount in the case we have considered, but approximately not more than 12 per cent. if we take the temperature of the fire at 3000°, the difference between 3000° and 1800° being absorbed in the furnace. But we should not gain even this *increase of power* if we double the length of the boiler

in order to obtain a corresponding increase in the length of tube, there being a great loss of heat due to radiation into the atmosphere from the boiler shell, which loss increases directly as the length, and beyond a certain limit it is evident that we should lose more than we should gain by adding to the length of the boiler

On the other hand, by reducing the length of the boiler too much, a large quantity of heat would be wasted, owing to the excessively high temperature at which the gases would escape. As a rule we should make our heating surface as great as possible, taking care to discharge the products of combustion at a sufficiently high temperature to ensure a good draught and not to waste more heat by radiation from the boiler than is transmitted by the heating surface. The temperature of the escaping products should not exceed 600°, which is about the maximum in good practice and the best for ensuring a good draught.

5. The evaporative efficiency of a given amount of heating surface depends upon the time allowed for the transmission of heat through it, or for the contact of the hot gases. The greater their velocity, the less time have they for imparting their heat to the plates or tubes where the length of surface is constant. The velocity through a tube may be increased, either by reducing its area, the total quantity of gases passing through remaining constant, or by increasing the draught, and so causing a greater amount of gases to pass through in a given time, the area of the tube remaining unaltered. When the heating surface consists chiefly of tubes, as in the locomotive type of boiler, the collective area of the tubes may be diminished without decreasing the extent of heating surface, since the sectional area varies as the square of the diameter, whilst the surface measured by the circumference diminishes simply as the diameter. With the gases passing at the same velocity through two tubes, whose diameters are as 1: 2, the latter will be traversed in a given time by four times the quantity of gases, and will have only twice the surface to absorb the heat. Therefore, to obtain the same evaporative economy as in the small tube, we must double the length of the larger, or generally speaking the proportion between diameter and length of a tube is constant for the same evaporative efficiency. When an increased quantity of gases of the same density pass through a tube in a given time, although there will be a greater absorption of heat, there will still be a loss by the increased amount of heat remaining in the escaping

gases; and in order to preserve the same economy, or in order that the heat of the escaping gases shall remain constant, the length of the tube must be increased in proportion to the increased quantity of gases passed through.

If we consider the heat to be imparted to the tube surface by radiation, which, however slight, is probably the principal mode of transfer in vertical and other long tubes, where the convection amongst the particles of gas cannot be supposed to take place to any great extent, we may assume the heat to be concentrated in the axis of the tube, whence we find the quantity of heat received in a given time by the surface from radiation will be inversely as the square of the diameter. By doubling the diameter we shall have four times the quantity of gases passed through, and the quantity of heat received in a given time will be only one quarter of what it was before, owing to the increase of distance. The surface being, however, twice as great, the absorption per unit of length becomes equal to one-half the original. Therefore, in order to bring the evaporative efficiency up to the original, we must double the length of tube, or generally we must increase the heating surface as the square of the diameter, in order to obtain the same evaporative efficiency from radiation when increasing the diameter of a tube.

But if we reduce the diameter to one-half, we increase the absorbing power fourfold per unit of surface; the heating surface being however reduced to one-half, the evaporative power of the tube will be only doubled, whence the tube may be reduced to one-half the original length and still retain the same evaporative efficiency, or, the length remaining unaltered, the quantity of gases passing through should be doubled to maintain the same temperature at the escaping end, or, as before, the efficiency of each square foot of heating surface increases inversely as the square of the diameter.

When a fuel is used which burns with a long flame, the diameter of the tubes should not be too small to exclude the flame altogether from passing along them, as it is of much more evaporative value than the transparent products of combustion, owing to the small radiating effect of the latter. But where the hydro-carbons and carbonic oxide can be sufficiently burnt before reaching the tubes these can scarcely be made too small. In locomotive furnaces the presence of the brick or water arch, by retarding the passage of the gases to the tubes and giving more time for the proper combustion of the volatile parts of the

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fuel should render successful the application of still smaller tubes than are generally used.

6. From what has already been stated concerning the small amount of heat transmitted by radiation, conduction, and convection from the transparent gaseous products of combustion, the heating surface, at a distance from the furnace, in order to be effective, should be arranged to bring the gases in direct contact with it, by suddenly changing the direction of their current, or by placing water tubes in their path, but at the same time the arrangement must not impair the draught to a serious degree.

The evaporative value of a square foot of heating surface varies then in different classes of boilers as well as in the same boiler, according to its condition, nature, position, &c. In consequence of this and the uncertainty of the other conditions on which depends the evaporative power, there is considerable difficulty in determining precisely the area of heating surface necessary for the production of a given amount of steam. The simplest way to estimate the evaporative power of a boiler is to take the average duty of the whole heating surface found by experience for the various descriptions of boilers in use. We may take the average maximum evaporative effect of a square foot of heating surface at 21 lbs. of water per hour, or one cubic foot of water evaporated by three square feet of surface. It will be more than this in some locomotive fireboxes, and wherever a jet of flame impinges violently againt the surface, and less in some furnaces of externally fired boilers. The precise value has never yet been found. In locomotive boilers the highest average value for the whole surface in the boiler is 13·5 lbs. of water from one foot of surface, or about 1 cubic foot of water from about 4½ square feet of surface; and in ordinary tubular and externally fired boilers from 3 to 7 lbs., or 1 cubic foot from 21 to 9 square feet of heating surface, ranging from 20 lbs. per square foot of furnace surface to a few ounces or nil per square foot at the point where the gases quit the boiler.

For a given description of boiler, it is evident the evaporative efficiency will mainly depend upon the ratio between the quantity of coal consumed and the extent of heating surface. The quality of the fuel and the manner in which it is burnt, as well as the condition of the heating surface, have necessarily an important influence upon the evaporative efficiency and power. As we have already seen, there may be considerable latitude allowed in determining the ratio of consumption to heating

surface. By slightly increasing the draught and burning more fuel, or, in other words, by slightly forcing the fire, we may materially increase the speed of evaporation with a very small loss of economy ; and, on the other hand, we might add very greatly to the heating surface without finding any appreciable benefit either in speed or economy.

The small gain in economy, accompanying an increase of heating surface, is most marked when the area added is parallel with the current of gases, and at the part of the boiler where they quit it and where it can be least effective, being actod upon only by the radiant heat from the gases. But if the additional surface is placed in the furnace so as to absorb an additional quantity of the radiant heat from the fire, or arranged so as to receive the heat of the flame and gases by direct contact, which may be done by diminishing the diameter and increasing the number of tubes in a multitubular or water-tube boiler, or by placing an efficient feed-water heater between the boiler and chimney with which the gases come in direct contact, the economy may be maintained whilst the consumption of fuel and speed of evaporation is increased.

Mr. D. K. Clark, who has carefully investigated the relations of grate area, heating surface, and consumption of fuel and water in locomotive boilers, arrives at the following conclusions :—

1. For a given extent of heating surface the economical hourly consumption of fuel or water decreases directly as the grate area is increased, and consequently in order to maintain the same efficiency or economical effect, the total hourly consumption should be reduced at the same rate as the grate area is increased.

2. For a given area of grate the total hourly consumption should vary as the square of the heating surface. That is, if we double the area of heating surface, we can burn four times the quantity of fuel with the same grate area and maintain the same evaporative efficiency or economy.

3. For a given hourly consumption the area of the firegrate should vary as the square of the heating surface in maintaining the same efficiency. That is, if the heating surface be doubled, the grate area may be increased four times, and the same economical consumption maintained.

Now with respect to the first of these conclusions, it would appear to hold good for all descriptions of boilers. In general it may *be said that* there cannot be too little grate area for

economical evaporation. Evaporative economy is, however, not compatible with evaporative speed, and the diminution of grate area is limited by the speed of evaporation required, and by the maximum rate of combustion found to be consistent with economy, which varies in different classes of boilers. By reducing the grate area the economical value of the heating surface of the boiler may be increased, although the speed of evaporation may at the same time be diminished. From the relations embodied in the second and third conclusions, that when the heating surface is doubled the economical hourly consumption of fuel may be increased fourfold by increasing the rate of combustion or the size of the grate, it may be concluded that the efficiency of each foot of surface is increased by merely increasing the surface, or that the evaporative power of the boiler is increased more rapidly than the increase of heating surface, whilst the efficiency is maintained. There is, however, a maximum quantity of coal that can be economically burnt on each square foot of grate, which limits the power to be derived by increasing the heating surface, while the grate area remains constant, and with a given rate of consumption of fuel the increase of grate area is limited by practical considerations already noticed.

It is, however, more especially to boilers of the locomotive type that the two last conclusions can apply. In adding heating surface to a locomotive boiler with a given area of firegrate, we can only increase the size of firebox, add midfeathers or similar expedients, and increase the number of tubes, as the length of boiler cannot usually be increased. This at once adds considerably to the economical evaporative power, by offering a larger surface at the most effective position in the boiler; and if the diameter of the tubes be at the same time reduced, the evaporative efficiency is likely to be still further increased, as the smaller tubes are better adapted for extracting the heat from the gases, and the result found in practice agrees with the theoretical considerations advanced above.

But in the case of an ordinary stationary boiler we can only augment the heating surface to any considerable extent by adding to the length of the boiler, or by increasing the run of the flues. In either case we add the heating surface where it is least effective, and where the least quantity of water is evaporated, in consequence of the gases being here cooler, and in the worst condition for imparting their heat, and also on account of a deposit of soot and incrustation being thickest where the

gases quit the boiler for the chimney. By doubling the length of a tubular or externally fired boiler we should not be able even to double the consumption of fuel and maintain the same evaporative economy. Besides, unless the draught can be materially increased at the same time that the run of the flues is lengthened there will be a decided falling off in the speed of evaporation.

In the locomotive the forced draught allows a greater range in the rate of combustion than can be obtained in stationary and marine boilers.

With a sluggish draught small tubes are liable to become choked up with soot or flue deposit, and this liability increases with the length of the tube. The same remark applies to a great extent to external flues, where the tendency of the soot to adhere to and accumulate upon the plates increases with the length of flue and sluggishness of draught. In multitubular boilers with chimney draught the ratio of the length to the diameter of tube should not exceed 24 : 1. In locomotives it may be made as much as 120 : 1. The reduction of the diameter of the tubes is limited by the area of the flue way it is found necessary to maintain, which will greatly depend upon the strength of the draught. In multitubular boilers with chimney draught the ratio of total tube area to grate area should be about 1 : 7. In locomotives the proportion of the collective sectional area of tubes to grate area is usually about 1 : 4. With a constant proportion of grate area and flue way, the grate is reduced to one-half by doubling the quantity of tubes of a given length, and still maintaining the same quantity of heating surface in them. As twice the quantity of fuel should be burnt on this reduced area to maintain the same efficiency, it follows that four times the quantity of fuel is to be burnt per hour per square foot of grate. The practical impossibility of exceeding a certain rate of combustion should restrict the reduction of the diameter of the tubes. With a given length of boiler the reduction of the diameter of tubes is limited by the ratio of diameter and length of tube it is advisable to adhere to. At the Wigan coal trials in 1868 the effect was tried of dispensing with the external flues of a Lancashire and Galloway boiler, the gases being allowed to pass directly from the internal flues to the chimney. The result was a slight falling off in economy, or in pounds of water evaporated per pound of coal; but very nearly the same quantity of water was evaporated as when the gases made the circuit of the external flues, and consequently

traversed a much larger extent of heating surface. It was also found that the Galloway boiler was not superior in evaporative power or economy to the ordinary Lancashire boiler, although it possesses a greater extent of effective heating surface, and also that the difference between the evaporative effect of iron and steel flues in a Lancashire boiler was not appreciable. In all these cases a high rate of evaporative efficiency was maintained, being above 9 lb. of water from 100° per lb. of coal; but had there been a considerably larger consumption of coal per hour, giving a higher temperature to the escaping gases, the result would have been more decidedly in favour of the larger heating surface of the Galloway boiler, and of both boilers with external flues, as compared with the results without them.

There are cases, however, of boilers having two internal furnaces, with combustion chambers, and a number of small tubes at back end, which, notwithstanding their greater heating surface, cannot be made to generate steam as rapidly or as economically as boilers of the simple Lancashire type working alongside of them, and having the same external length and diameter, the same grate area, chimney, and description of external flues, and other conditions. This unlooked-for result can only be ascribed to the decrease of draught and the increased quantity of incrustation and soot caused by the more complicated arrangement of flue way. With a cleaner fuel and purer water it is not improbable that the results would be reversed.

There are numerous cases where the additional surface of conical and other water tubes is rendered almost useless by the amount of incrustation formed in them. The incrustation accumulates more rapidly inside these small tubes than on the convex surface of the main tubes they are placed in, in spite of the circulation, chiefly owing to the greater difficulty found in removing the incrustation as it forms, caused by its inaccessibility. Greater pains should therefore be bestowed in cleaning out these water tube boilers in order to maintain their efficiency. It may be gathered from these last considerations that the evaporative result obtained from a new boiler may afford no guide to the value of the same boiler after it has been in use some time.

The comparative amount of hard incrustation is generally a pretty sure index of the value of the heating surface on which it is found. Where the ebullition is greatest, the amount of hard and tenacious scale will be least. This, however, does not apply

where the boiling off of the deposit is impeded by stays or other obstacles, such as are found on the crown of some locomotive fire-boxes, or in the midst of a nest of closely packed small tubes. In some cases where the boiler is not carefully cleaned, the line which marks the limit of the greatest ebullition over the furnaces of externally fired and internally flued boilers, and in the water tubes, may be found pretty sharply defined by the variation in the thickness of incrustation, especially where the circulation is defective. The change in the colour of the incrustation caused by the heat when the furnace plates have been accidentally left bare of water, with a good fire underneath, sometimes reveals the fact that the intense heat over the fire, both from the radiation of the incandescent fuel and the impinging flames, is much greater than the heat imparted by the flame alone. The buckling of the plates caused by overheating under similar circumstances is usually confined to the crown in front of or above the bridge, and is also an indication of the greater intensity of the heat at this part.

The most satisfactory method of determining the efficiency of any heating surface is that given by Professor Rankine, which is as follows :—

$$\frac{E'}{E} = \frac{BS}{S + AF}$$

Where $E' =$ the available evaporative power, and $E =$ the theoretical evaporative power of 1 lb. of a given kind of fuel in an ordinary boiler in which $S =$ the total area of heating surface, including feed water heater, if any ; $F =$ the number of pounds of fuel burnt per hour. A and B are two constants found by experience ; A is probably approximately proportionate to the square of the quantity of air supplied per lb. of fuel. B is a fractional multiplier to allow for miscellaneous losses of heat, which, for chimney draught, is here taken at 20 per cent.

For boilers with chimney draught $B = \frac{4}{5} \quad A = \cdot 5$

,, ,, ,, forced ,, $B = \frac{19}{20} \quad A = \cdot 3$

The following are examples of efficiency for different proportions of boilers and rates of combustion, with chimney draught calculated by means of this formula :—

	Square foot of heating surface per lb. of fuel per hour.	Efficiency of furnace.	Pounds of water at 212° evaporated by 1 lb. of coal.	Pounds of steam at 60 lbs. pressure per lb. of coal from feed at 62°.
Very small.	·50	·4	5·6	4.7
For Egg-ended Cornish, Lancashire, and Multitubular Boilers.	·75	.48	6·72	5·7
	1·00	·53	7·42	6·3
	1·25	·56	7·48	6·6
	1·50	·60	8·4	7·1
	1·75	·62	8·68	7·4
	2·00	·64	8·96	7·6
For Water-tube and Cellular Boilers.	3·00	·69	9.66	8·1
	4·00	·71	9.94	8·4
	5·00	·72	10·0	8·5
	6·00	·73	10·2	8·6

The third and fourth columns give the average rate of evaporation of boilers in use, the total heat from 1 lb. of coal being taken at 14 lbs. of water evaporated from 212°. With a clean boiler, good coal, skilful firing, and introducing the feed water at a high temperature, the quantities in column four may be increased by from 10 to 30 per cent.; and on the other hand, with a dirty boiler and unskilful attendance they may be diminished from 65 to 20 per cent., which is too frequently the case, and often causes much disappointment. With the best descriptions of feed water heaters, or economisers, which utilise the heat from the escaping gases on their way to the chimney, and have their surface at right angles to the direction of the draught kept clear by means of self-acting scrapers, the feed may at times be raised to a temperature of 250°, or even more, with a corresponding saving in fuel. The area of these economisers should be considered in estimating the efficiency of the total heating surface of the boiler.

The plan sometimes adopted of placing an old boiler or tank in the flue between the end of the boilers and chimney to serve as a feed water heater, is often attended with very unsatisfactory results, owing to the absorbing surface becoming thickly coated over with soot when smoky coals are used. There are instances

of such feed-warmers heating the water to about 212° for the first few days after being set to work; but their efficiency gradually falls off, and sometimes at the end of a fortnight they are unable to raise the temperature of the water they contain beyond 100°, simply owing to the thick non-conducting coating of soot they receive.

There are many Cornish and Lancashire boilers, where due attention is not paid to cleaning the flues, working for months together with an inch or more of soot on the bottom plates in the external flues, and with a large quantity of flue deposit in the internal tubes, varying in thickness from that limited by the height of the bridge to 6″ or 9″ at the back end. In fact, the usual state of affairs is not much better than this after working a few weeks with ordinary descriptions of semi-bituminous coal, and a great part of the heating surface is rendered useless in consequence.

CHAPTER XVI.

BOILER POWER.

It must be admitted that the manner in which the power of a boiler is usually calculated is far from satisfactory. It has long been the custom to estimate boilers by their real or nominal horse power. As the nominal horse power of an engine is usually based upon the diameter of the cylinder, without regard to other conditions, so in boilers the nominal standard of power is estimated by their size, without regarding the pressure of steam, the efficiency of heating surface, size of grate, rate of combustion, quality of coal, setting, and frequently the most important of all, the condition of the boiler and ability of the firemen. Whilst admitting their unsatisfactory nature, we shall give some of the rules that have been mostly employed. However correct any one of these rules may be for one description of boiler, it will give a false result for boilers of a different class, or even of the same class, but of different size and proportions.

Armstrong's rule is to allow one cubic foot of water evaporated per hour, one square foot of firegrate area, and one square yard of total heating surface per horse power for ordinary coal, and $\frac{3}{4}$ of a square foot of grate for good steam coal, and as little as $\frac{1}{2}$ square foot when the best coal only is employed. This rule stands $H\,P = \frac{1}{2}(S + G)$ where $S =$ heating surface in yards, and $G =$ area of fire grate in feet. Reckoning by superficies it is now usual to allow about 15 square feet of heating surface per nominal horse power for ordinary factory boilers. For multitubular boilers from 18 to 26 square feet of heating surface, and from ·5 to ·85 square feet of grate area.

Another rule very much used is to allow from 5 to 6 square feet of boiler section per H. P. in plain cylindrical boilers, or

$$H\,P = \frac{\text{section of Boiler}}{6}$$

In Cornish and Lancashire boilers the sectional area of the *flue tubes* is usually added, and from 6 to 8 square feet per

H. P. is allowed. For example, in a Lancashire boiler 7 feet diameter, 30 feet long, and having 2 flues 2′ 9″ diameter, we have 375 square feet of section, which divided by 8, gives 47 H. P. For Galloway boilers 4·5 is usually taken for a divisor instead of 6.

Another rule like Armstrong's is

$$H\,P = \sqrt{S \times G}$$

For multitubular boilers the following rule is sometimes used :

$$H\,P = 1{\cdot}8\sqrt{S \times G}$$ S being in yards and G in feet.

For marine boilers working up to nearly five times their nominal horse power—

$$H\,P = {\cdot}7\sqrt{S \times G}$$

As the term nominal horse power, according to these rules, is so undefined, it is preferable to reckon the power of a boiler by the quantity of water it will evaporate. With a moderately good engine one half cubic foot of water, or about 30 lbs., will develop 1 H. P. (indicated) per hour. With externally fired boilers having the proportions between the heating surface and grate area between the limits of 10 and 16 to 1, the average evaporative power may be taken at 1 cubic foot from 18 feet of heating surface, or 9 feet per H. P. Egg-ended furnace boilers, intensely heated their whole length, have been known to evaporate 1 cubic foot of water from 4 square feet of heating surface, which is equivalent to 2 square feet per H. P. In Cornish and Lancashire boilers, where the proportions between the heating surface and grate area are within the limits of 15 and 25 to 1, the evaporative power may be taken at 1 cubic foot of water from about 14 square feet of total heating surface, or 7 square feet per indicated horse power.

In multitubular and other boilers where the heating surface is to the grate area as from 30 : 1 to 40 : 1, 9 square feet of surface will evaporate 1 cubic foot of water, or require $4\frac{1}{2}$ square feet of total heating surf ce per H. P.

Vertical boilers are usually very wasteful of fuel, but in some cases, where the boiler is in good condition, and the circulation

is promoted by well arranged water tubes, they have evaporated 8 lbs. of water from 60° per 1 lb. of coal, and 1 cubic foot of water per hour from 16 square feet of heating surface, and may be reckoned at 8 square feet per H. P.; but 10 or 12 square feet per H. P. are more commonly required.

In locomotive boilers with forced draught, and the ratio of heating surface to grate area between 60 : 1 and 80 : 1, an average of 3 square feet of total heating surface per indicated H. P. may be taken as an approximation. As we have already said, the quality of fuel, rate of combustion, skill of stoker, arrangement of furnace, and condition of boiler, will materially influence these quantities.

Suppose we require the size of a Cornish boiler to supply steam to an engine having a cylinder 16″ diameter and 24″ stroke, making 60 revolutions a minute, cutting off at one quarter stroke, and working at 60 lbs. pressure. Now, without taking into account the difference of pressure in the boiler and in the cylinder, we shall have the quantity of steam required per hour thus:—$16^2 \times \cdot 7854 \times \cdot 25 \times 24 \times 2 \times 60 \times 60 = 5026$ cubic feet. This quantity should be increased by at least 25 per cent., to allow for loss of steam in ports, clearance of piston, escape at safety valve, and other waste, as well as to allow some margin of power; we shall therefore have 6282 cubic feet as the quantity of steam to be evaporated per hour. In table at page 303 we find that at 60 lbs. pressure 1 cubic foot of steam is 353 times more bulky than the water from which it is raised, whence the above quantity of steam is equivalent to $17\frac{3}{4}$ cubic feet, or 1106 lbs., of water evaporated at 60 lbs. pressure per hour.

The usual rate of combustion in Cornish boilers is about 12 lbs. of coal per square foot of grate area; and taking the evaporation at 7·25 lbs. from 60° per lb. of coal, we get $12 \times 7{\cdot}25 = 87$ lbs. of water evaporated per square foot of grate per hour, and $1106 \div 87 = 12\frac{3}{4}$ square feet of grate, the area required. Fixing the maximum length at 5 feet, the width will be 2′ 7″, which will require a tube of about 2′ 9″ diameter. Allowing 6 inches for bottom water space, and 2′ 3″ from furnace crown to shell crown, we have a boiler 5′ 6″ diameter; and taking the length at four times the diameter, we shall have 22 feet as the length.

Had the area of firegrate required been about 20 square feet, it would have been advisable to limit the length of grate to 4 feet, and to make a Lancashire boiler 7 feet diameter × 28

feet long, having two 2′ 9″ tubes, instead of making the grate 6′ 0″ × 3′ 4″, and using a Cornish boiler 6′ 0″ diameter, with a 3′ 6″ furnace tube.

Many tests have been undertaken to ascertain the evaporative power of different classes of boilers in actual work; but few of these are of any value, owing to the unreliable means usually employed to measure the quantity of water evaporated. The easiest method, and consequently the one most frequently adopted, is to measure the quantity by the difference of its height in the water-gauge glass at the beginning and end of the trial, and also at intermediate stages. This method is very rude and uncertain, since there can be little doubt that in many boilers at work the surface of the water is not level, but is usually higher over the furnace, or where the greatest ebullition occurs. The difference in height at any moment will greatly depend upon the intensity of the ebullition which is ever varying during the intervals between firing. With mechanical firing the difference of height is probably reduced to a minimum.

The meters employed for measuring the water are sometimes not trustworthy. The only sure method of ascertaining the quantity of water evaporated is by actual measurement with a cistern or vessel, whose cubic contents are accurately known. The quantity of water in the boiler before and after the trial should be measured at the same temperature, which should not exceed 212° to ensure accuracy. But even when the amount of water introduced and the quantity passed off from the boiler is accurately ascertained, there yet remains a doubt as to how much has been actually evaporated, and how much may have passed off in priming, unless the trial has been conducted with the boiler open to the atmosphere, which appears to be the only condition under which accuracy can be ensured, unless a suitable apparatus can be provided for accurately measuring the weight and temperature of all the steam and water given off when the boiler is working above atmospheric pressure.

There are very few boilers that do not prime more or less, and the quantity of water passed off in this manner is sometimes very considerable, and has led to the impossible results of 16 and 17 lbs. of water evaporated per lb. of ordinary coal in locomotive and water tube boilers being seriously recorded. Externally fired boilers that have given the moderate result of 5 lbs. of water per lb. of coal at atmospheric pressure, have shown the unexpected result of 10 and 12 lbs. of water evaporated at 40 lbs. pressure. In fact, unless the amount of water passed

over with the steam by priming, when working under pressure, can be accurately ascertained, the evaporative results are not to be relied upon, however carefully in other respects the trial may have been conducted.

It is customary to give the quantity of water evaporated from a temperature of 212°, *to* which the results of evaporation are usually reduced.

The quantity corresponding to any temperature of feed water and working pressure can readily be found with the aid of the annexed table, taken from the "Encyclopædia Britannica," wherein are presented the relations of the properties of steam, as now accepted by the best authorities :—

Properties of Saturated Steam.

Total pressure per square inch measured from a vacuum.	Pressure above atmosphere.	Sensible temperature in Fahrenheit degrees.	Total heat in degrees from zero of Fahrenheit.	Weight of one cubic foot of steam.	Relative volume of steam compared with water from which it was raised.
1	—	102·1	1144·5	·0030	20582
2	—	126·3	1151·7	·0058	10721
3	—	141·6	1156·6	·0085	7322
4	—	153·1	1160·1	·0112	5583
5	—	162·3	1162·9	·0138	4527
6	—	170·2	1165·3	·0163	3813
7	—	176·9	1167·3	·0189	3298
8	—	182·9	1169·2	·0214	2909
9	—	188·3	1170·8	·0239	2604
10	—	193·3	1172·3	·0264	2358
11	—	197·8	1173·7	·0289	2157
12	—	202·0	1175·0	·0314	1986
13	—	205·9	1176·2	·0338	1842
14	—	209·6	1177·3	·0362	1720
14·7	0	212.0	1178·1	·0380	1642
15	·3	213·1	1178·4	·0387	1610
16	1·3	216·3	1179·4	·0411	1515
17	2·3	219·6	1180·3	·0435	1431
18	3·3	222·4	1181·2	·0459	1357
19	4·3	225·3	1182·1	·0483	1290
20	5·3	228·0	1182·9	·0507	1229
21	6·3	230·6	1183·7	·0531	1174
22	7·3	233·1	1184·5	·0555	1123
23	8·3	235·5	1185·2	·0580	1075
24	9·3	237·8	1185·9	·0601	1036
25	10·3	240·1	1186·6	·0625	996
26	11·3	242·3	1187·3	·0650	958
27	12·3	244·4	1187·8	·0673	926
28	13·3	246·4	1188·4	·0696	895
29	14·3	248·4	1189·1	·0719	866
30	15·3	250·4	1189·8	·0743	838
31	16·3	252·2	1190·4	·0766	813
32	17·3	254·1	1190·9	·0789	789
33	18·3	255·9	1191·5	·0812	767
34	19.3	257·6	1192·0	·0835	746
35	20·3	259·3	1192·5	·0858	726
36	21·3	260·9	1193·0	·0881	707
37	22·3	262·6	1193·5	·0905	688
38	23·3	264·2	1194·0	·0929	671
39	24·3	265·8	1194·5	·0952	655
40	25·3	267·3	1194·9	·0974	640

Properties of Saturated Steam.

Total pressure per square inch measured from a vacuum.	Pressure above atmosphere.	Sensible temperature in Fahrenheit degrees.	Total heat in degrees from zero of Fahrenheit.	Weight of one cubic foot of steam.	Relative volume of steam compared with water from which it was raised.
41	26·3	268·7	1195·4	·0996	625
42	27·3	270·2	1195·8	·1020	611
43	28·3	271·6	1196·2	·1042	598
44	29·3	273·0	1196·6	·1065	585
45	30·3	274·4	1197·1	·1089	572
46	31·3	275·8	1197·5	·1111	561
47	32·3	277·1	1197·9	·1133	550
48	33·3	278·4	1198·3	·1156	539
49	34·3	279·7	1198·7	·1179	529
50	35·3	281·0	1199·1	·1202	518
51	36·3	282·3	1199·5	·1224	509
52	37·3	283·5	1199·9	·1246	500
53	38·3	284·7	1200·3	·1269	491
54	39·3	285·9	1200·6	·1291	482
55	40·3	287·1	1201·0	·1314	474
56	41·3	288·2	1201·3	·1336	466
57	42·3	289·3	1201·7	·1364	458
58	43·3	290·4	1202·0	·1380	451
59	44·3	291·6	1202·4	·1403	444
60	45·3	292·7	1202·7	·1425	437
61	46·3	293·8	1203·1	·1447	430
62	47·3	294·8	1203·4	·1469	424
63	48·3	295·9	1203·7	·1493	417
64	49·3	296·9	1204·0	·1516	411
65	50·3	298·0	1204·3	·1538	405
66	51·3	299·0	1204·6	·1560	399
67	52·3	300·0	1204·9	·1583	393
68	53·3	300·9	1205·2	·1605	388
69	54·3	301·9	1205.5	·1627	383
70	55·3	302·9	1205·8	·1648	378
71	56·3	303·9	1206·1	·1670	373
72	57·3	304·8	1206·3	.1692	368
73	58·3	305·7	1206·6	·1714	363
74	59·3	306·6	1206·9	·1736	359
75	60·3	307·5	1207·2	·1759	353
76	61·3	308·4	1207·4	·1782	349
77	62·3	309·3	1207·7	·1804	345
78	63·3	310·2	1208·0	·1826	341
79	64·3	311·1	1208·3	·1848	337
80	65·3	312·0	1208·5	·1869	333
81	66·3	312·8	1208·8	·1891	329

Properties of Saturated Steam.

Total pressure per square inch measured from a vacuum.	Pressure above atmosphere.	Sensible temperature in Fahrenheit degrees.	Total heat in degrees from zero of Fahrenheit.	Weight of one cubic foot of steam.	Relative volume of steam compared with water from which it was raised.
82	67·3	313·6	1209·1	·1913	325
83	68·3	314·5	1209·4	·1935	321
84	69·3	315·3	1209·6	·1957	318
85	70·3	316·1	1209·9	·1980	314
86	71·3	316·9	1210·1	·2002	311
87	72·3	317·8	1210·4	·2024	308
88	73·3	318·6	1210·6	.2044	305
89	74·3	319.4	1210·9	·2067	301
90	75·3	320·2	1211·1	·2089	298
91	76·3	321·0	1211·3	·2111	295
92	77·3	321·7	1211·5	·2133	292
93	78·3	322·5	1211·8	.2155	289
94	79·3	323·3	1212·0	·2176	286
95	80·3	324·1	1212·3	·2198	283
96	81·3	324·8	1212·5	·2219	281
97	82·3	325·6	1212·8	·2241	278
98	83·3	326·3	1213·0	·2263	275
99	84·3	327·1	1213·2	·2285	272
100	85·3	327·9	1213·4	·2307	270
101	86·3	328·5	1213·6	·2329	267
102	87·3	329·1	1113·8	·2351	265
103	88·3	329·9	1214·0	·2373	262
104	89·3	330·6	1214·2	·2393	260
105	90·3	331·3	1214·4	·2414	257
106	91·3	331·9	1214·6	·2435	255
107	92·3	332·6	1214·8	·2456	253
108	93·3	333·3	1215·0	·2477	251
109	94·3	334·0	1215·3	·2499	249
110	95·3	334·6	1215·5	·2521	247
111	96·3	335·3	1215·7	·2543	245
112	97·3	336·0	1215·9	·2564	243
113	98·3	336·7	1216·1	·2586	241
114	99·3	337·4	1216·3	·2607	239
115	100·3	338·0	1216·5	·2628	237
116	101·3	338·6	1216·7	·2649	235
117	102·3	339·3	1216·9	·2674	233
118	103·3	339·9	1217·1	·2696	231
119	104·3	340·5	1217·3	·2738	229
120	105·3	341·1	1217·4	·2759	227
121	106·3	341·8	1217·6	·2780	225
122	107·3	342·4	1217·8	·2801	224

Properties of Saturated Steam.

Total pressure per square inch measured from a vacuum.	Pressure above atmosphere.	Sensible temperature in Fahrenheit degrees.	Total heat in degrees from zero of Fahrenheit.	Weight of one cubic foot of steam.	Relative volume of steam compared with water from which it was raised.
123	108·3	343·0	1218·0	·2822	222
124	109·3	343·6	1218·2	·2845	221
125	110·3	344·2	1218·4	·2867	219
126	111·3	344·8	1218·6	·2889	217
127	112·3	345·4	1218·8	·2911	215
128	113·3	346·0	1218·9	·2933	214
129	114·3	346·6	1219·1	·2955	212
130	115·3	347·2	1219·3	·2977	211
131	116·3	347·8	1219·5	·2999	209
132	117·3	348·3	1219·6	·3020	208
133	118·3	348·9	1219·8	·3040	206
134	119·3	349·5	1220·0	·3060	205
135	120·3	350·1	1220·2	·3080	203
136	121·3	350·6	1220·3	·3101	202
137	122·3	351·2	1220·5	·3121	200
138	123·3	351·8	1220·7	·3142	199
139	124·3	352·4	1220·9	·3162	198
140	125·3	352·9	1221·0	·3184	197
141	126·3	353·5	1221·2	·3206	195
142	127·3	354·0	1221·4	·3228	194
143	128·3	354·5	1221·6	·3250	193
144	129·3	355·0	1221·7	·3273	192
145	130·3	355·6	1221·9	·3294	190
146	131·3	356·1	1222·0	·3315	189
147	132·3	356·7	1222·2	·3336	188
148	133·3	357·2	1222·3	·3357	187
149	134·3	357·8	1222·5	·3377	186
150	135·3	358·3	1222·7	·3397	184
155	140·3	361·0	1223·5	·3500	179
160	145·3	363·4	1224·2	·3607	174
165	150·3	366·0	1224·9	·3714	169
170	155·3	368·2	1225·7	·3821	164
175	160·3	370·8	1226·4	·3928	159
180	165·3	372·9	1227·1	.4035	155
185	170·3	375·3	1227·8	·4142	151
190	175·3	377·5	1228·5	·4250	148
195	180·3	379.7	1229·2	·4357	144
200	185·3	381·7	1229·8	·4464	141
210	195·3	386·0	1231·1	·4668	135
220	205.3	389·9	1232·3	·4872	129
230	215·3	393·8	1233·5	·5072	123

Properties of Saturated Steam.

Total pressure per square inch measured from a vacuum.	Pressure above atmosphere.	Sensible temperature in Fahrenheit degrees.	Total heat in degrees from zero of Fahrenheit.	Weight of one cubic foot of steam.	Relative volume of steam compared with water from which it was raised.
240	225·3	397·5	1234·6	·5270	119
250	235·3	401·1	1235·7	·5471	114
260	245·3	404·5	1236·8	·5670	110
270	255·3	407·9	1237·8	·5871	106
280	265·3	411·2	1238·8	·6070	102
290	275·3	414·4	1239·8	·6268	99
300	285·3	417·5	1240·7	·6469	96

Here we see that at 212° the total quantity of heat in the steam is 1178° ·1, which gives a difference of 966°·1. This heat, usually termed latent, is absorbed in performing the work of expanding the particles of water from the solid to the gaseous state. Now, suppose the water is evaporated at 60 lbs. pressure, the steam will have a temperature of 307°, and a total heat of 1207°. If the feed has been introduced at 60°, it is evident that 1147° of heat have been imparted. As the amount evaporated is inversely proportional to the quantity of heat required, we have 1147 ÷ 966 = 1·2. Multiplying by this factor, the quantity evaporated at 60 lbs. pressure from 60°, we obtain the amount that would be evaporated at 212° by the same quantity of fuel.

By the same table can be ascertained the comparatively small increase of heat required to evaporate water at higher pressures. Suppose we take water evaporated at 45 lbs. pressure from a feed temperature of 60°, then each lb. of water will require 1202·7—60 = 1142·7° for its conversion into steam. If we take the pressure at 100 lbs. we shall have 1216·9—60 = 1156·9° as the quantity required. The difference between these two total quantities is only 14·2°, and is so small as to be scarcely worth considering. Leaving out of account the loss due to the slight reduction of the conducting power of the material, the increased amount of heat required for the higher pressure will be only $\frac{1}{80}$ of the total heat required at 60 lbs. With an evaporation of 7 lbs. of water from 1 lb. of coal, it will be obtained by using $\frac{1}{383}$ more fuel, or about 1 lb. in about $5\frac{1}{2}$ cwt.,

a quantity not appreciable in the ordinary modes of weighing coal. The economy is then manifest of using steam of high pressure, when at the same time advantage is taken of the facilities it offers for working expansively in the cylinder.

The saving that may be effected by heating the feed water may be shown as follows :—If we take the normal temperature of the feed water at 60°, the temperature of the heated water at 212°, and the boiler pressure at 20 lbs., the total heat imparted to the steam in one case is 1192°·5 —60 ° = 1132°·5, and in the other case 1192·5 — 212 = 980°·5, the difference being 152°, or a saving of $\frac{152}{1132 \cdot 5}$ = 13·4 per cent.

If the pressure be taken at 120 lbs. instead of 20 lbs. the saving will be 13·1 per cent., showing a slight diminution in the economy effected by heating the water when a high pressure in the boiler is employed.

The loss from blowing off when fresh water is used may be found as follows. Supposing the ratio of the quantity of water evaporated to that blown out is 10 : 1, we have with a pressure of 20 lbs. and a feed temperature of 100°—

Evaporated	10 (1192°·5 — 100°) =	10925	heat units	
Blown out	1 (259·3 — 100°) =	159·3	„	„
	Total =	11084·3	„	„

showing a loss of only 1·4 per cent. of the total heat imparted.

With a pressure of 100 lbs. we should have a corresponding loss of 2 per cent.

The effect of the presence in a liquid of any substance in solution is to resist ebullition, and to raise the boiling point. In ordinary fresh water the slight increase in the elevation of temperature, due to the presence of salts in solution, is generally disregarded ; but in salt water, partially saturated, the increase is of some practical importance. The boiling point of saturated brine is 226°, and that of weaker brine is higher than the boiling point of pure water by 1°·2 for each $\frac{1}{32}$ of salt the water contains. The quantity contained by average sea water is usually taken as $\frac{1}{32}$. The loss of heat by blowing out when salt water is used can easily be calculated for any pressure and degree of saltness. Assuming the temperature of the feed water to be 105°, at a pressure of 20 lbs., and a saltness of $\frac{2}{32}$, the temperature of the water in the boiler will be 261°·7, the corresponding total heat of the steam being 1194·9, and the quantity

of water to be blown out is equal to the quantity evaporated. We have then :—

$$\begin{aligned} \text{For evaporation } 1 & \left\{ \begin{matrix} (1194^\circ{\cdot}9 - 105^\circ) = 1089{\cdot}9 \text{ heat units.} \\ (\ \ 261{\cdot}7 - 105\ ) = \ \ 156{\cdot}7 \ \ \text{,,} \quad \text{,,} \end{matrix} \right. \\ \text{blown out } 1 & \\ & \qquad\qquad \text{Total} = 1246{\cdot}6 \ \ \text{,,} \quad \text{,,} \end{aligned}$$

Consequently the heat lost by blowing out is $\frac{156{\cdot}7}{1246{\cdot}6}$ or 12.6 per cent. of the total heat imparted.

In the same manner it will be found for a degree of saturation of $\frac{3}{32}$, when the quantity of water to be blown out will be ·5 the quantity evaporated, that the loss of heat by blowing off will be only 6·7 per cent. of the total heat imparted.

CHAPTER XVII.

BURSTING AND COLLAPSING PRESSURES OF CYLINDERS

BURSTING PRESSURE.

THE following table of the strength of cylindrical shells to resist internal bursting pressure in a direction parallel to their axis is calculated by this approximate formula—

$$P = \frac{T \times c}{D.}$$

where P = bursting pressure in lbs. per square inch,
T = thickness of cylinder in sixteenths,
D = diameter of shell in quarter feet,
c = a constant, being,

$$\left.\begin{array}{l}1097 \text{ for single riveting} \\ 1372 \text{ for double riveting}\end{array}\right\} \text{wrought iron,}$$

$$\left.\begin{array}{l}1723 \text{ for single riveting} \\ 2156 \text{ for double riveting}\end{array}\right\} \text{steel.}$$

Bursting Pressure of Lap-Jointed Wrought-Iron Cylindrical Shells.

Diameter of Shell.		Bursting pressure in lbs. per square inch.		Diameter of Shell.		Bursting pressure in lbs. per square inch.		Diameter of Shell.		Bursting pressure in lbs. per square inch.	
$\frac{5}{16}$ plates.	$\frac{5}{8}$ plates.	Single riveting.	Double riveting.	$\frac{3}{8}$ plates.	$\frac{3}{4}$ plates.	Single riveting.	Double riveting.	$\frac{7}{16}$ plates.	$\frac{7}{8}$ plates.	Single riveting.	Double riveting.
′ ″	′ ″			′ ″	′ ″			′ ″	′ ″		
2 0	4 0	686	857	3 0	6 0	548	685	3 6	7 0	563	704
2 3	4 6	609	761	3 3	6 6	506	632	3 9	7 6	512	640
2 6	5 0	548	685	3 6	7 0	470	612	4 0	8 0	480	600
2 9	5 6	499	624	3 9	7 6	439	539	4 3	8 6	452	565
3 0	6 0	457	571	4 0	8 0	411	514	4 6	9 0	426	532
3 3	6 6	422	527	4 3	8 6	387	484	4 9	9 6	404	505
3 6	7 0	392	490	4 6	9 0	366	457	5 0	10 0	384	480
3 9	7 6	366	457	4 9	9 6	346	432	5 3	10 6	366	457
4 0	8 0	343	429	5 0	10 0	329	411	5 6	11 0	349	436
4 3	8 6	322	403	5 3	10 6	313	391	5 9	11 6	333	416
4 6	9 0	304	380	5 6	11 0	299	374	6 0	12 0	320	400
4 9	9 6	288	360	5 9	11 6	286	358	6 3	12 6	307	384
5 0	10 0	274	342	6 0	12 0	274	342	6 6	13 0	295	369
5 3	10 6	261	326	6 3	12 6	263	329	6 9	13 6	284	355
5 6	11 0	249	311	6 6	13 0	253	316	7 0	14 0	274	342
5 9	11 6	238	297	6 9	13 6	244	305	7 3	14 6	265	331
6 0	12 0	228	285	7 0	14 0	235	294	7 6	15 0	256	320
6 3	12 6	219	273	7 3	14 6	227	284	7 9	15 6	247	309
6 6	13 0	211	264	7 6	15 0	220	275	8 0	16 0	240	300
6 9	13 6	203	254	7 9	15 6	212	265	8 3	16 6	233	291
7 0	14 0	196	245	8 0	16 0	205	256	8 6	17 0	226	282

Bursting Pressure of Lap-Jointed Wrought-Iron Cylindrical Shells.

Diameter of Shell.		Bursting pressure in lbs. per square inch.		Diameter of Shell.		Bursting pressure in lbs. per square inch.	
½ plates.	1 plates.	Single riveting.	Double riveting.	$\frac{9}{16}$ plates.	1⅛ plates.	Single riveting.	Double riveting.
′ ″	′ ″			′ ″	′ ″		
4 0	8 0	548	685	4 0	8 0	617	771
4 3	8 6	516	645	4 3	8 6	581	726
4 6	9 0	487	609	4 6	9 0	548	685
4 9	9 6	462	577	4 9	9 6	520	650
5 0	10 0	439	549	5 0	10 0	494	617
5 3	10 6	418	522	5 3	10 6	470	588
5 6	11 0	399	499	5 6	11 0	449	561
5 9	11 6	381	476	5 9	11 6	429	536
6 0	12 0	365	457	6 0	12 0	411	514
6 3	12 6	351	439	6 3	12 6	395	494
6 6	13 0	337	421	6 6	13 0	380	475
6 9	13 6	325	406	6 9	13 6	366	457
7 0	14 0	312	390	7 0	14 0	352	440
7 3	14 6	302	377	7 3	14 6	341	426
7 6	15 0	292	365	7 6	15 0	330	412
7 9	15 6	283	354	7 9	15 6	319	399
8 0	16 0	274	342	8 0	16 0	308	385
3 3	16 6	266	332	8 3	16 6	299	374
8 6	17 0	258	322	8 6	17 0	290	362
8 9	17 6	250	312	8 9	17 6	282	352
9 0	18 0	243	304	9 0	18 0	274	342

Collapsing Pressures.

:E following tables give the strength of tubes of perfectly .ar form, or not more than about the thickness of plate the true circle. As the shape of long tubes, especially of large diameter, is very irregular, and liable to undergo ıdual change, from the heat being applied chiefly at the ı, and from the resistance to expansion caused by rigidity ıe end plates, to say nothing of the sudden distortion r to arise from incrustation and the use of thick or greasy :, a large factor of safety should be allowed for the ng-off pressure of the boiler. This should in no case be han 4, and in new boilers, in which the pressure is so after a time increased, a factor of not less than 6 should rs be allowed.

e tables are calculated by this approximate formula—

$$P = \frac{262 \cdot 4 \times T^2}{L \times D}$$

P = collapsing pressure in lbs. per square inch,
T = thickness of tube in thirty-seconds,
L = length in feet,
D = diameter in quarter feet.

I.—*Collapsing Pressures of Wrought-Iron Cylindrical Tubes* $\frac{1}{4}$ *inch thick.*

Length in feet.	Diameter of Tube in inches.													
	9	12	15	18	21	24	27	30	33	36	39	42	45	48
4	1398	1049	840	699	600	525	466	420	382	349	323	300	280	262
6	932	698	560	466	400	349	311	285	254	233	215	200	187	174
8	699	524	420	350	300	262	233	210	191	175	161	150	140	131
10	559	419	336	280	240	210	186	168	152	140	129	120	112	105
12	466	349	285	233	200	175	155	142	127	116	107	100	95	87
14	400	300	239	200	171	150	133	120	109	100	92	85	79	75
16	350	262	210	175	150	131	117	105	95	87	81	75	70	65
18	311	233	187	156	133	116	103	95	85	78	72	66	62	58
20	278	210	168	140	120	105	93	84	76	70	64	60	56	52
22	255	190	153	128	109	95	85	76	69	64	58	55	51	47
24	233	174	142	116	100	87	78	71	63	58	53	50	47	43
26	215	161	129	107	92	80	72	64	58	54	49	46	43	40
28	200	150	120	100	85	75	67	60	54	50	46	43	40	37
30	186	140	112	93	80	70	62	56	51	46	43	40	37	35
32	175	131	105	87	75	65	58	52	47	44	40	37	35	32
34	164	123	99	82	70	61	55	49	45	41	38	35	33	30
36	155	116	94	77	66	58	51	47	42	39	36	33	31	29

II.—*Collapsing Pressures of Wrought-Iron Cylindrical Tubes $\frac{5}{16}$ inch thick.*

Length in feet.	Diameter of Tube in inches.													
	9	12	15	18	21	24	27	30	33	36	39	42	45	48
4	2187	1640	1312	1093	937	820	729	656	596	546	504	468	437	410
6	1458	1093	875	729	624	546	486	437	398	364	336	312	292	273
8	1093	820	656	546	468	410	364	328	298	273	252	234	218	205
10	875	656	525	437	374	328	292	262	238	218	202	187	178	164
12	729	546	437	364	312	273	243	218	199	182	168	156	146	136
14	625	468	375	312	267	324	208	182	170	156	144	133	125	162
16	546	410	328	273	234	205	182	164	149	136	126	117	109	102
18	486	364	292	243	208	182	162	146	133	121	112	104	97	91
20	437	328	262	218	187	164	146	131	119	109	101	93	87	82
22	398	298	238	199	170	149	133	119	108	99	91	85	79	74
24	364	273	218	182	156	136	121	109	99	91	84	78	73	68
26	336	252	202	168	144	126	112	101	92	84	77	72	67	63
28	312	234	187	156	133	117	104	93	85	78	72	66	62	58
30	291	218	175	145	125	109	97	87	79	72	67	62	58	54
32	273	205	164	136	117	102	91	82	74	68	63	58	55	51
34	257	193	154	128	110	96	86	77	70	64	59	55	51	48
36	243	182	146	121	104	91	81	73	66	60	56	52	48	45

III.—*Collapsing Pressures of Wrought-Iron Cylindrical Tubes* $\frac{3}{8}$ *inch thick.*

Length in feet.	Diameter of Tube in inches.													
	9	12	15	18	21	24	27	30	33	36	39	42	45	48
4	3148	2361	1889	1574	1349	1180	1049	944	858	787	726	674	629	590
6	2099	1574	1260	1049	900	787	699	630	572	525	484	450	420	393
8	1574	1180	944	787	674	590	525	472	429	393	363	337	315	295
10	1260	945	756	630	540	472	420	378	344	315	291	270	252	236
12	1050	787	630	520	450	393	350	315	286	260	242	225	210	196
14	900	674	540	450	385	337	300	270	245	225	208	198	180	168
16	787	590	472	393	337	295	262	236	214	196	181	168	157	147
18	699	525	420	350	300	262	233	210	191	175	161	150	140	131
20	630	472	378	315	270	236	215	189	172	157	145	135	126	118
22	573	429	343	286	245	214	191	171	156	143	132	122	114	107
24	525	393	315	262	225	196	175	157	143	131	121	112	105	98
26	484	363	292	242	207	181	161	146	132	121	112	103	97	90
28	450	337	270	225	192	168	150	135	122	112	104	96	90	84
30	420	315	252	210	180	157	140	126	115	105	97	90	84	79
32	393	295	236	196	168	147	131	118	107	98	90	84	79	73
34	370	278	222	185	158	139	123	111	101	92	85	79	74	69
36	350	262	210	175	150	131	117	105	95	87	80	75	70	65

IV.—*Collapsing Pressures of Wrought-Iron Cylindrical Tubes $\frac{7}{16}$ inch thick.*

Length in feet.	Diameter of Tube in inches.													
	9	12	15	18	21	24	27	30	33	36	39	42	45	48
4	4786	3214	2571	2143	1837	1607	1428	1285	1169	1071	989	918	857	803
6	2857	2143	1714	1428	1224	1071	952	857	780	714	659	612	571	535
8	2143	1607	1285	1021	918	803	714	642	584	510	494	459	428	401
10	1714	1286	1028	857	735	643	571	514	468	428	396	367	343	321
12	1428	1071	857	714	612	535	476	428	390	357	330	306	286	267
14	1224	918	735	612	525	459	408	367	333	306	282	262	245	230
16	1071	803	642	536	459	401	357	321	292	268	247	229	214	200
18	952	714	571	476	408	357	317	285	260	238	220	204	190	178
20	857	643	514	428	367	321	289	257	234	214	198	183	171	160
22	779	584	468	390	334	292	260	234	212	195	180	167	156	146
24	714	536	428	357	306	268	238	214	195	178	165	153	143	134
26	659	494	396	330	282	247	220	198	180	165	152	141	132	123
28	612	459	367	306	262	230	204	183	167	153	141	131	122	115
30	571	428	342	285	245	214	190	171	156	142	132	122	114	107
32	536	401	321	268	229	201	179	160	146	134	124	114	107	100
34	504	378	302	252	216	189	168	151	137	126	116	108	101	94
36	476	357	285	238	204	178	159	142	130	119	110	102	98	89

V.—*Collapsing Pressures of Wrought-Iron Cylindrical Tubes ½ inch thick.*

Length in feet.	Diameter of Tube in inches.													
	9	12	15	18	21	24	27	30	33	36	39	42	45	48
4	5598	4193	3359	2799	2399	2096	1866	1680	1526	1400	1292	1200	1120	1048
6	3732	2799	2239	1866	1599	1400	1244	1120	1018	933	861	800	746	700
8	2799	2096	1680	1400	1200	1048	933	840	763	700	646	600	560	524
10	2239	1679	1344	1120	960	840	746	672	611	560	518	480	448	420
12	1866	1400	1120	933	790	700	622	560	509	466	430	395	373	350
14	1599	1200	960	799	685	600	533	480	436	400	369	342	320	300
16	1400	1048	840	700	600	524	467	420	381	350	323	300	280	262
18	1244	933	746	622	533	466	415	373	339	311	287	266	249	233
20	1119	840	672	560	480	420	373	336	305	280	259	240	224	210
22	1018	763	610	509	436	381	336	305	277	254	235	218	203	195
24	933	700	560	466	400	355	311	280	254	233	215	200	187	177
26	861	646	517	430	369	323	287	258	235	215	198	184	172	161
28	799	600	480	400	342	300	266	240	218	200	184	171	160	150
30	746	560	448	373	320	280	249	224	204	186	172	160	149	140
32	700	524	420	350	300	262	233	210	190	175	161	150	140	131
34	658	494	395	329	2[illegible]2	247	219	197	180	164	152	141	132	123
36	622	466	373	311	267	233	207	174	170	156	143	133	124	116

VI.—*Collapsing Pressures of Wrought-Iron Cylindrical Tubes $\frac{9}{16}$ inch thick.*

Length in feet.	Diameter of Tube in inches.													
	9	12	15	18	21	24	27	30	33	36	39	42	45	48
4	7085	5313	4251	3542	3038	2656	2362	2126	1932	1771	1635	1519	1417	1328
6	4723	3542	2834	2361	2024	1771	1574	1417	1288	1180	1089	1012	945	885
8	3542	2656	2126	1721	1519	1328	1181	1063	966	860	817	760	708	664
10	2834	2125	1700	1417	1214	1062	945	850	773	708	654	607	570	531
12	2361	1771	1417	1180	1012	885	787	708	644	590	544	506	472	442
14	2024	1518	1214	1012	868	759	675	607	552	506	467	434	405	380
16	1771	1328	1063	885	760	664	590	531	483	442	408	380	354	332
18	1574	1181	945	787	675	590	525	472	429	393	363	387	315	295
20	1407	1062	850	703	607	531	472	425	386	351	327	303	283	266
22	1288	966	773	644	552	483	429	386	351	322	297	276	258	241
24	1180	885	708	590	506	442	393	354	322	295	272	253	236	221
26	1090	817	654	545	467	408	363	327	297	272	251	233	218	204
28	1012	759	607	506	434	380	337	303	276	253	233	217	202	190
30	945	708	566	475	405	354	315	283	258	237	218	202	188	179
32	885	664	531	442	380	332	295	265	242	221	204	190	177	166
34	833	625	500	416	357	312	278	250	227	208	192	178	166	156
36	787	590	472	393	337	295	262	236	214	197	181	163	157	147

VII.—*Collapsing Pressures of Wrought-Iron Cylindrical Tubes $\frac{5}{8}$ inch thick.*

Length in feet.	Diameter of Tube in inches.													
	9	12	15	18	21	24	27	30	33	36	39	42	45	48
4	8747	6560	5248	4373	3748	3280	2916	2624	2385	2186	2018	1874	1749	1690
6	5831	4373	3498	2916	2499	2186	1944	1749	1590	1458	1346	1250	1166	1093
8	4373	3280	2624	2186	1874	1640	1458	1312	1192	1043	1009	987	875	820
10	3498	2624	2099	1749	1499	1312	1166	1050	954	874	807	750	699	656
12	2916	2186	1749	1458	1249	1093	972	874	795	729	673	625	583	546
14	2500	1874	1499	1250	1071	937	833	750	682	625	577	535	499	468
16	2186	1640	1312	1093	937	820	729	656	596	546	504	468	437	410
18	1944	1458	1166	972	833	729	648	583	530	486	448	416	388	364
20	1799	1312	1049	900	750	656	600	525	477	450	403	375	349	328
22	1590	1193	954	795	683	596	530	477	434	397	367	341	318	298
24	1458	1093	874	729	624	546	486	437	397	364	336	312	291	273
26	1345	1009	808	672	577	504	448	404	367	336	311	288	269	252
28	1250	937	749	625	535	468	417	374	341	312	288	267	250	234
30	1166	875	700	583	499	437	388	350	318	291	269	249	233	218
32	1093	820	656	546	463	410	364	328	298	273	252	232	218	205
34	1029	772	617	514	441	386	343	308	280	257	237	220	205	193
36	972	729	583	486	416	364	324	291	265	243	224	208	194	182

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